SUPERCONDUCTIVITY UNDER IRRADIATION CONDITIONS

L. A. Rott

UDC 530.145+539.945

The irradiation effect of a particle flow on the electrodynamic properties of a conductor is discussed. It is established that a relationship exists between three energy quanta of different origin and high-temperature superconduction current.

The influence of irradiation on superconductor properties receives ever-increasing attention in experimental physics. Investigation of this effect yields important new results in the field of high-temperature superconductivity (HTSC). This is also of crucial importance for the general SC theory.

It has been shown previously [1] that superconductivity develops due to an additional intermolecular interaction which is stable at a temperature lower than the critical one. In turn, the established interaction, which influences the orientational ordering of the entire system, is caused by the initial induced current. Such a conclusion is based on a quantum-mechanical approach that accounts for the successive transformation of the number of particles, whose character is an inherent dynamic property of the system.

Since a real atom is an inhomogeneous system (AB), then it is necessary, within the framework of the considered formalism, to take into account the presence of two energy quanta directly related to subsystems A and B. A magnetic-field quantum ε_H absorbed by subsystem A (a nucleus with a meson cloud) determines the rearrangement of electron sybsystem B with transition energy ε_E and creation of a current with density j. The quantum ε_E determines, in turn, the additional molecular bond in the presence of an electric current.

The energy quanta introduced for magnetic and electric fields, respectively, are represented in the form

$$\varepsilon_H = \mathrm{h}_H \mathrm{H} \quad \text{and} \quad \varepsilon_E = \mathrm{h}_E \mathrm{E}. \tag{1}$$

Using $h_H(h_E)$ in combination with two fundamental constants, we introduce the corresponding units of length and time:

$$l_H = \frac{h_H}{\sqrt{\hbar c}}, \quad t_H = \frac{h_H}{\sqrt{\hbar c^3}}. \tag{2}$$

Considering ε as an energy quantum of an arbitrary physical field, we can also write the following expression for it

$$\varepsilon = \mathrm{h}_g \Delta \mathrm{r}, \tag{3}$$

in which Δr is an elementary shift for a finite interval of time Δt_g. Now with the aid of the three quantities $\hbar$, c, and h_g we obtain a new system of units

$$l_g = \sqrt{\left(\frac{\hbar c}{h_g}\right)}, \quad t_g = \sqrt{\left(\frac{\hbar}{h_g c}\right)} \tag{4}$$

and using the latter write an expression for the velocity $\mathrm{v} = (\Delta \mathrm{r})/(\Delta t_g)$ assuming $t_g = \Delta t_g$:

$$v = \sqrt{\left(\frac{\varepsilon c \Delta r}{h}\right)}, \quad h = 2\pi\hbar. \tag{5}$$

Belarus State Technological University Minsk, Belarus. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 68, No. 5, pp. 739-742, September-October, 1995. Original article submitted January 18, 1994.

Expressions (1) may be represented in the form of (3)

$$\varepsilon_H = \mathrm{F}_H \Delta \mathrm{r}\,, \quad \varepsilon_E = \mathrm{F}_E \Delta \mathrm{r}\,, \tag{6}$$

where F_H is the Lorentz force and $\mathrm{F}_E = e_{\mathrm{E}}$.

When the magnetic and electric fields are mutually perpendicular (the vector $\Delta\mathrm{r}$ is collinear with E), using (5) for $v = c$ we arrive at

$$l_E^2 = \frac{e^2 \hbar c}{\varepsilon_E^2}\,, \tag{7}$$

and the important general relations

$$\frac{\varepsilon_E}{\varepsilon_H} = \frac{l_H}{l_E} = \frac{h_H}{h_E} < 1\,. \tag{8}$$

In superconductivity theory two quantities l_H and l_E correspond to two linear dimensions, namely, the London length δ and the correlation parameter ξ. The critical temperature is defined in terms of ε_E

$$T_{\mathrm{cr}} = \frac{\varepsilon_E}{k}\,. \tag{9}$$

Here ε_E is the known energy gap Δ.

In complex molecules forming HTSCs, more than one quantum transition with a change in the collective energy level is realized, which inevitably causes enhancement of the intermolecular interaction potential and, as a consequence, an increase in the critical parameters (rupture of the addiitonal intermolecular bond means SC failure).

Using the Maxwell equations, we find the relationship between the energy quanta ε_H and ε_E and the current j [1]:

$$\frac{\partial \varepsilon_H}{\partial t} = \frac{\partial \varepsilon_E}{\partial t} + 4\pi \mathrm{h}_E \mathrm{j}\,. \tag{10}$$

In the presence of superconductly, the derivative $\partial\varepsilon_H/\partial t$ vanishes and then from (10) the equations stem which are analogous to the Ginzburg-Landau equations in the SC theory (see [2], p. 217).

The situation becomes substantially more complicated when the conductor, irradiated by a particle flux, is capable of absorbing the particles. Then, in addition to the energy quanta ε_H and ε_E, we must consider the energy quantum ε_m, in which is equal to the kinetic energy of an absorbed particle. All three quanta belong to different atom subsystems, whose transformational quantum-mechanical properties form, as a whole, a system of the ABC type (the energy quantum ε_m is absorbed by the nucleus, ε_H by a nuclear cloud, and ε_E pertains to the electron subsystem C).

It is to be expected that, instead of Eq. (10), the following relationship takes place between the aforementioned three energy quanta and the current

$$\frac{\partial \varepsilon_m}{\partial t} = \frac{\partial \varepsilon_H}{\partial t} - \frac{\partial \varepsilon_E}{\partial t} - 4\pi \mathrm{h}_E \mathrm{j}\,. \tag{11}$$

In the absence of irradiation, it becomes (10). But in the case of irradiation, all three quantities, i.e., ε_H, ε_E, and j, undergo changes. We will substantiate the sought relation.

We proceed from the fact that the vector-potential of an electromagnetic field A must be represented as a sum of two terms

$$\mathrm{A} = \mathrm{A}_0 + \mathrm{A}_1\,(\mathrm{A}_0\,,\ \mathrm{B})\,, \tag{12}$$

where the second term is a result of the influence of additional irradiation. The vector **A** depends, naturally, on the initial vector-potential A_0 (in the absence of irradiation $A_1 \equiv 0$) and on the vector **B**, which is independent of it. This is due to the fact that the spectrum of the levels of the deep subsystem (in the used quantum-mechanical formalism) changes the spectra of the intermediate and, respectively, of the partially collectivized electron subsystems.

Following the variational principle in deriving the Maxwell equations (see [3]), we must, however, proceed now from the independence of δA_{0i} and δB_i variations. This implies that two fields (magnetic and particle fields) are independent of each other.

The tensor components containing the projections of the vectors of magnetic and electric intensities can be written as a sum of two terms

$$H_i = H_{0i} + M_{Hi} \quad \text{and} \quad E_i = E_{0i} + M_{Ei} .$$

Thus, for instance, the tensor element $F_{12} = -F_{21}$ is written as

$$F_{12} = H_{0z} + M_{0z} .$$

If the first pair of Maxwell equations is formally written in the previous form, the second pair is represented in the modified form owing to the above circumstances. The first of the second pair of Maxwell equations is written in the form

$$\operatorname{rot} \mathbf{H} - \frac{1}{c}\frac{\partial \mathbf{H}}{\partial t} = \frac{4\pi}{c}(\alpha_x \mathbf{j}_x + \alpha_y \mathbf{j}_y + \alpha_z \mathbf{j}_z) , \tag{13}$$

where

$$\alpha_i = 1 \bigg/ \left(1 + \frac{\partial A_{1i}}{\partial A_{0i}}\right) , \quad i = x,\ y,\ z . \tag{14}$$

When $\mathbf{M} = 0$ ($\partial A_{1i}/\partial A_{0i} \equiv 0$), (13) turns into the classical Maxwell equation.

We now perform scalar multiplication of (13) by the vector $\mathbf{h}_E$ and multiplication of the first Maxwell equation of the first pair by $\mathbf{h}_H$. Considering the definitions of (1) and the assumption that h_i is independent of time, we arrive at the equation

$$\frac{\partial \varepsilon_H}{\partial t} - \frac{\partial \varepsilon_E}{\partial t} - 4\pi \mathbf{h}_E (\alpha_x \mathbf{j}_x + \alpha_y \mathbf{j}_y + \alpha_z \mathbf{j}_z) = -c\,(\mathbf{h}_H \operatorname{rot} \mathbf{E} + \mathbf{h}_E \operatorname{rot} \mathbf{H}) . \tag{15}$$

Next, we designate the right-hand side of (15) as $\partial \varepsilon_m / \partial t$, thus introducing the energy quantum ε_m. Then (15) can be reduced to a form similar to (11) but with a significant correction:

$$\frac{\partial \varepsilon_m}{\partial t} = \frac{\partial \varepsilon_H}{\partial t} - \frac{\partial \varepsilon_E}{\partial t} - 4\pi \beta \mathbf{j} , \tag{16}$$

where

$$\beta = \beta\,(h_{Ex}\alpha_x ,\ h_{Ey}\alpha_y ,\ h_{Ez}\alpha_z) .$$

When $\varepsilon_m = 0$, $\beta = \mathbf{h}_E$ and we obtain the known Eq. (10).

In turn, the energy quantum $_m$ can be written in field form, and ε_H and ε_E, in terms of the intensity of the hypothetic field **M**:

$$\varepsilon_m = \mathbf{h}_m \mathbf{M} . \tag{17}$$

Considering that, according to [1],

$$\mathbf{h}_H \operatorname{rot} \mathbf{E}_0 + \mathbf{h}_E \operatorname{rot} \mathbf{H}_0 = 0 ,$$

then

$$\frac{\partial \varepsilon_m}{\partial t} = -c\,(\mathbf{h}_H \operatorname{rot} \mathbf{M}_E + \mathbf{h}_E \operatorname{rot} \mathbf{M}_H)\,. \tag{18}$$

From the modified Maxwell equations it follows now that

$$\frac{1}{c}\frac{\partial \mathbf{M}_H}{\partial t} = -\operatorname{rot} \mathbf{M}_E\,, \tag{19}$$

$$\frac{1}{c}\frac{\partial \mathbf{M}_E}{\partial t} = \operatorname{rot} \mathbf{M}_H - \frac{4\pi}{c}\,(\alpha_x \mathbf{j}_x + \alpha_y \mathbf{j}_y + \alpha_z \mathbf{j}_z) + \frac{4\pi}{c}\,\mathbf{j}_0\,, \tag{20}$$

where $\mathbf{j}_0$ is the vector of the current density in the absence of irradiation.

Let us evaluate h_m. With the aid of h_m and $\hbar$, c we introduce the unit length l_m analogously to (2)

$$l_m = \frac{h_m}{\sqrt{\hbar c}}\,. \tag{21}$$

On the other hand, according to the general expression (5) ε_m is

$$\varepsilon_m = \frac{h v^2}{c\,\Delta z}\,. \tag{22}$$

Equating (22) to the kinetic energy of a particle of mass m, we find

$$\Delta r = \frac{2h}{mc}\,. \tag{23}$$

From $\Delta r = l_m$ it follows finally that

$$l_m = \frac{2h}{mc}\,, \quad h_m = \frac{2\hbar^{3/2}}{mc^{1/2}}\,. \tag{24}$$

Hence we obtain the following estimates: $h_m \sim 10^{-21}$ CGS and $l_m \sim 10^{-14}$, i.e., l_m indicates the characteristic scale of nuclear processes (a particle is absorbed by a nucleus).

We now return to Eq. (16). Generation of a high-temperature superconduction current means that the derivative $\partial \varepsilon_m/\partial t$ vanishes. At the same time the derivative $\partial \varepsilon_H/\partial t$ now differs from zero which means weakening of the Meissner effect under high-temperature superconductivity conditions. An important experimental problem in the light of the developed theory is the determination of current variation under the same conditions, especially the determination of numerical α_i values.

NOTATION

$\hbar$, Planck constant; c, velocity of light; **H**, magnetic intensity; **E**, electric intensity; **r**, radius-vector; ε_m, ε_H, ε_E, energy quanta; l_g, unit length; **j**, electric current; **A**, vector-potential of the electromagnetic field; F_{ik}, field tensor; m, mass of the absorbed particle; v, velocity; l_H, l_E, l_m, length units; t, time; e, electron charge; k, Boltzmann constant; T_{cr}, critical temperature.

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