Nonresonant supermigration in concentrated ruby samples

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We observed experimentally a shortening of the migration time of the electron-excitation energy between laser-excited single Cr^{3+} ions and Cr^{3+}–Cr^{3+} exchange pairs at a temperature 1.8 °K.

As shown in[1], laser excitation of optical centers in a crystal at pulse durations $\tau_p < T_1$, T_2, T_2^* (T_1, T_2, and T_2^* are respectively the times of longitudinal, transverse reversible, and transverse irreversible phase relaxation) causes supermigration (SM), which becomes manifest in an appreciable shortening of the time t_0 of incoherent migration of the energy of the electron excitation. When the energy is transferred between centers whose excited states ($\hbar\omega_d$ or $\hbar\omega_a$, where $d(a)$ designates a donor (acceptor)) differ by an amount $\hbar(\omega_d - \omega_a) \leq \hbar\omega_D$ (ω_D is the Debye frequency), the time t_{SM} of the nonresonant SM is described by the formula[2,3]:

$$t_{SM} = \frac{(2\omega_d - \omega_d)}{\omega_d l^2 N_0^2 \lambda^4} \left(\frac{T_2}{T_2^*}\right)^2 t_0 = \gamma t_0, \qquad (1)$$

where N_0 cm^{-3} is the number of acceptors, $\lambda = 2\pi c \omega_d^{-1} n^{-1}$, c is the speed of light, n is the refractive index, l is the sample thickness, $T_2 \approx 10^{-10} C_0^{-1}$, and C_0 is the concentration in atomic units.

We have investigated experimentally the nonresonant SM between the system of isolated Cr^{3+} ions and exchange-coupled Cr^{3+}–Cr^{3+} pairs in ruby samples with Cr^{3+} concentration 0.5% and 1.5% at a temperature $T = 1.8$ °K. These samples had $T_2 = (1-2)\times 10^{-8}$ sec, and the value of T_2^* obtained experimentally by us for the N_2 line was $(1.8-2)\times 10^{-11}$ sec; according to (1) we have $\gamma \approx 10^{-3}$. The K_1 line of the ions was excited by a ruby laser with active Q-switching. The ruby rod was cooled with liquid nitrogen, τ_p did not exceed 10 nsec. The luminescence of the R_1 and N_2 lines was separated with a monochromator and was observed on the screen of a long-persistent two-beam oscilloscope S1-42. The experimental setup is shown in Fig. 1.

The presented formula (1) describes the time during which half the acceptor particles go into the excited state as a result of migration from the donor system. In view of the fact that the time scale in Fig. 2a is large and t_{SM} is small, Fig. 2a does not make it possible to determine the value of t_{SM}. However, the decay time obtained from this oscillogram agrees well with data by others.[4,5] This indicates that the spontaneous decay of the N_2 line proceeds incoherently. And since the intensity of incoherent luminescence is proportional to the population of the excited states of the N_2 line, it follows that t_{SM} is the time necessary to reach half the maximum intensity of the N_2-line luminescence. To determine the order of magnitude it would be necessary to plot in greater detail the leading front of the N_2-line luminescence curve. The corresponding typical oscillograms are shown in Figs. 2b and 2c.

Performance of a number of measurements yielded $t_{SM} \approx 7\times 10^{-6}$ and $\approx 10^{-6}$ sec for Cr^{3+} concentrations 1.5% and 0.5%, respectively. At the same time, incoherent excitation of the donor impurities yields $t_0 \approx 10^{-3}$ sec,[6,7] i.e., the onset of the SM decreases the transfer time by a factor $\gamma \sim 10^{-3}$, in full agreement with (1). Some increase of t_{SM} for samples containing 1.5% Cr^{3+},

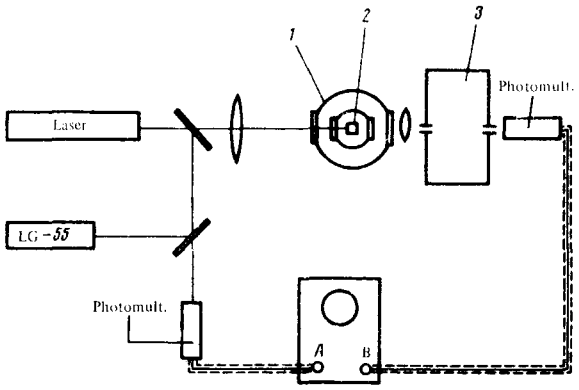

FIG. 1. Block diagram of experimental setup: 1—cryostat, 2—sample, 3—monochromator.

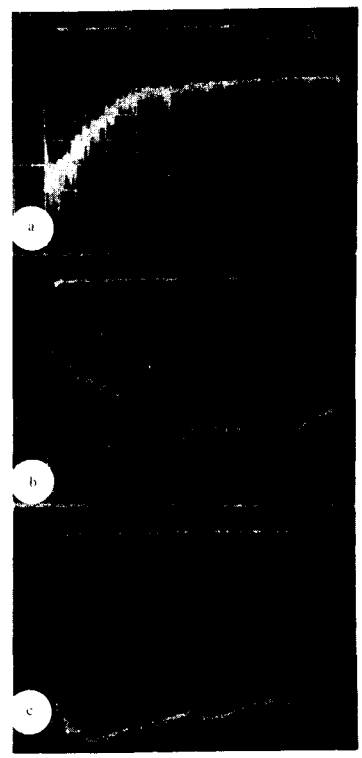

FIG. 2. Oscillograms of exciting pulse (top) and of the luminescence of the N_2 line: a) each square equals 500 μsec, 1.5% Cr^{3+}; b) each square equals 5 μsec, 1.5% Cr^{3+}; c) each square equals 5 μsec, 0.5% Cr^{3+}.

in comparison with less concentrated samples, is probably due to the decrease of T_2^* as a result of internal local magnetic fields.

Thus, this experiment demonstrates quite convincingly that the processes of interaction between different subsystems of a single quantum mechanical system can be intensified. This can become manifest not only in the appearance of SM, but also in an acceleration of the chemical, biological, and nuclear reactions when the subsystems are excited to a collective state.

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