ture, and incorporate several TR^{3+} ions and interstitial fluorine ions. The binding energies of these ions are lower than in the simpler-structure tetragonal centers. It is clear that the probability of destruction of more complicated centers is higher than that of the simpler ones.

2. Electron-hole mechanism. As a result of intense internal ionization accompanying the γ irradiation, a large number of electrons and holes are localized at various localization levels. In the case when the localization of the electrons or of the holes takes place sufficiently close to the TR^{3+} ion, the symmetry of its crystalline field changes, which is tantamount to formation of a center of a new type. This mechanism explains well the temperature instability of the crystal state produced following the irradiation, and the restoration of the initial structure of the centers. It is still unclear which of these mechanisms predominates.

It must be noted in conclusion that the effect observed in this investigation can be used for an analysis of the optical TR^{3+} centers in crystals by observing the inhomogeneous change in the absorption-line intensity following irradiation.

In addition, a study of the optical properties of the TR^{3+} centers in irradiated crystals can yield valuable information on the character of the processes which occur when hard radiation interacts with crystalline matter.

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IONIZATION OF AN ATOM COLLIDING WITH AN EXCITED ATOM

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1. In this paper we calculate the cross section of the reaction

$$A^* + B \to A + B^+ + e, \qquad (1)$$

with the excitation potential of atom A exceeding the ionization potential I of atom B. The assumption is used that the cross section of transition (1) is determined essentially by collision impact parameters which greatly exceed the dimensions of the colliding atoms. Transition (1) is an important process occurring in the gas discharge of a gas laser [1-3]. If the atom A^* is in a metastable state, reaction (1) is called the Penning effect and can be in-

vestigated experimentally [4-7]. We show in this paper that if the atom A* is in a resonant excited state from which a transition to the ground state via dipole radiation is possible, then the cross section of process (1) will be larger than in the case of the Penning effect. This means that the metastable A* atoms are more difficult to disintegrate by collision with the atom B than A* atoms in the resonant excited state.

2. In calculating the cross section of the process (1) we shall assume that the relative velocity v of the atom collisions is much smaller than the characteristic velocity of the electron in the atom. In this case the frequency W(R) of the decay of the quasimolecule A* + B at a given distance R between the nuclei does not depend on the velocities of the nuclei and on the probability $P(\rho, t)$ of ionization of the quasimolecule at the instant t, for a collision with impact parameter ρ, satisfies the equation:

$$\frac{dP(\rho, t)}{dt} = -[1 - P(\rho, t)]\, W(R). \tag{2}$$

Solution of (2) yields the probability of the transition (1) for collisions with impact parameter ρ:

$$P(\rho) = 1 - \exp[-\int_{-\infty}^{+\infty} W(R)dt]. \tag{3}$$

The probability per unit time W(R) of transition (1) with constant R (the frequency of the Auger effect of the quasimolecule), is equal to [8]:

$$W(R) = \frac{2\pi}{\hbar} |V_{12}(R)|^2 g_2, \tag{4}$$

where the indices 1 and 2 pertain to the states A* + B and $A + B^+ + e$ of the quasimolecule, and g_2 is the density of the final states. It is advantageous to choose here as the unperturbed Hamiltonian the sum of the Hamiltonians of the non-interacting atoms, and to choose as the perturbation V the interaction potential of these atoms

$$V = e^2\left(\frac{1}{R} + \frac{1}{|\vec{R} - \vec{r}_A + \vec{r}_B|} - \frac{1}{|\vec{R} - \vec{r}_A|} - \frac{1}{|\vec{R} + \vec{r}_B|}\right), \tag{5}$$

where $\vec{r}_A$ and $\vec{r}_B$ are the radius vectors of the atomic electrons measured from the nuclei corresponding to the given electron, and the vector $\vec{R}$ joins the nuclei.

3. We are considering the case when the cross section of process (1) is determined by a transition occurring when the distance between the atoms is large, so that the perturbation operator (5) can be expanded in powers of 1/R.

Two cases are of practical interest: (i) when A* is a metastable atom, and (ii) when it corresponds to a resonant excited state of the atom, from which a transition to the ground state by dipole radiation is possible. In the first case the matrix element of the operator (5) in terms of the wave functions of the ground and excited state of atom A is exponentially small at large distances between the atoms. This leads to a weak dependence of the cross section for the decay of the metastable atom on the velocity of collision with the other atom (it is proportional to $\ln^2(\text{const}/v)$). In addition, the cross section of the transition may

turn out to be insufficient, for the same reason, thus limiting the applicability of the asymptotic method used in this paper to obtain the cross section of the Penning effect.

4. When the excited state A* corresponds to the resonant state, we can confine ourselves in the operator (5) for transition (1), in the case of large R, to the dipole-dipole interaction:

$$V = \frac{e^2}{R^3}\left[\vec{r}_A\cdot\vec{r}_B - 3(\vec{r}_A\cdot\vec{n})(\vec{r}_B\cdot\vec{n})\right], \tag{6}$$

where $\vec{n}$ is a unit vector in the direction of $\vec{R}$. In calculating the cross section we shall assume that the atoms move on straight-line trajectories $\vec{R} = \vec{\rho} + \vec{v}\,t$ during the collisions and that the states of atom A are the s- and p-states. Resolving the direction of the momentum of the p-electron of atom A parallel and perpendicular to the velocity direction, we obtain with the aid of (3), (4), and (6) the cross section of the transition $\sigma = \int_0^\infty 2\pi\rho\, d\rho\, P(\rho)$ for each of the three possible cases. Averaging over the direction of the momentum of the p electron, we obtain the cross section of transition (1) in this case:

$$\sigma = \pi\Gamma\left(\frac{3}{5}\right)\left(\frac{e^2}{\hbar v}\right)^{2/5} a_0^2\left[\frac{2}{3}C^{2/5} + \frac{1}{3}\left(\frac{7}{2}C\right)^{2/5}\right] = 5.7\, a_0^2\left(\frac{Ce^2}{\hbar v}\right)^{2/5}. \tag{7}$$

Here $a_0 = \hbar^2/me^2$ is the Bohr radius, $C = (9cf_A\sigma_{phot}(\omega)/64\omega^2)/(m^4e^{10}/\hbar^9)$, c is the velocity of light, f_A the oscillator strength for the transition A* → A, and $\sigma_{phot}(\omega)$ the cross section for photoionization of atom B by a photon of frequency ω. Since usually $c\sigma_{phot}$ is of atomic magnitude, the coefficient C is of the order of unity, so that the cross section of the transition in question is $\sim v^{-2/5}$, i.e., at low collision velocities it is many times larger than the characteristic atomic magnitude. This justifies the use of the asymptotic method on the basis of which formula (7) has been derived.

The result obtained is valid if the width of the energy distribution function of the released electrons is much smaller than the average energy of these electrons $\hbar\omega - I$ ($\hbar\omega$ = excitation energy of atom A, I = ionization potential of atom B). The width of the electron distribution function is $\sim\hbar/\tau$, where τ is the average time of the Auger effect of the quasimolecule A* + B. Since the Auger-effect time for collisions making the main contribution to the cross section coincides with the collision time $\sim\rho/v$, the foregoing requirement yields $\omega - I/\hbar \gg v/\rho$ or

$$\sigma \gg v^2/(\omega - \frac{I}{\hbar})^2 \tag{8}$$

5. We shall use these results to determine the cross section of the reaction

$$Hg(6^1P_1) + Li(Cs) \rightarrow Hg(6^1S_0) + Li^+(Cs^+) + e. \tag{9}$$

This reaction plays a definite role in mhd generators operating with a lithium (cesium)-mercury mixture. Using the data of [9,10] for the oscillator strength of mercury and for the photoionization cross sections of lithium and cesium, we obtain on the basis of (7), for a relative-motion energy of the atoms 1500°K, values of 1.02×10^{-14} cm^2 and 3.5×10^{-15} cm^2 for the cross sections of lithium and cesium, respectively. The large values of the cross sections offer evidence of the correctness of the method used in their determination.

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IONIZATION OF DONOR ATOMS IN n-InSb BY A MICROWAVE ELECTRIC FIELD

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We have investigated the effect of a microwave electric field of wavelength λ = 10 mm on the electric conductivity of several samples of n-InSb, and observed that the microwave field ionizes the donor impurities. Owing to the small effective mass of the electrons, $m^* = 0.013\ m_0$, and owing to the large dielectric constant, $\epsilon = 16$, the wave functions of the donor-atom electrons in n-InSb overlap even at relatively low impurity concentrations, $\sim 5 \times 10^{14}$ cm^{-3}, and impurity conductivity comparable with the free-electron conductivity is observed at helium temperatures [1-3]. The experiments were therefore carried out with highly purified samples at temperatures down to 1°K. For two fixed temperatures, 4.2 and 1.1°K, at which the impurity conductivity is respectively comparable with the free-electron conductivity and is much larger than the latter, we plotted the Hall constant and the resistivity as functions of the microwave field power (Figs. 1 and 2). The measurements were made in a 3 kOe magnetic field. Samples measuring 2 x 0.5 x 10 mm were placed in front of a cylindrical waveguide, and the magnetic field was perpendicular to the plane of the sample. The sample parameters are shown in the table.

Sample Nos.	2	3	4	7	10	11
$N_D - N_A$, cm^{-3}	1.1×10^{13}	1.5×10^{13}	$3. \times 10^{13}$	4.4×10^{13}	$1. \times 10^{14}$	1.1×10^{14}
μ_H, cm^2/V-sec	2.6×10^5	1.6×10^5	8.4×10^4	2.9×10^5	3.7×10^5	$6. \times 10^3$