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Abstract

Full Text

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RESONANT TRANSFER OF EXCITATION AND CHANGE OF THE HYPERFINE STATE OF AN ATOM

(Presented by Academician M. A. Leontovich, 20 IX 1967)

1. A change in the direction of the spin of an atomic electron in the ground state may occur as a result of various processes. Direct reversal of the electron spin as a result of various kinds of magnetic interactions is unlikely because of the weakness of these interactions at low nuclear velocities. A change in the hyperfine state of an atom (determined by the total electronic and nuclear spin of the atom) is considerably more probable during exchange of electrons with opposite spins, occurring in the collision of two atoms ⁽¹⁾. The cross section of this process considerably exceeds the atomic cross section at low nuclear velocities ^(2,3).
2. It turns out that the electron spin of the ground state of an atom may also change during resonant transfer of excitation, whose probability at low nuclear velocities is considerably greater than the probability of electron exchange.

Resonant transfer of excitation is the process of exchange of electronic states in the collision of two identical atoms that are in states in which the absolute values of the electron orbital angular momentum differ by unity. In this case, at large distances R between the nuclei, the principal interaction is the dipole-dipole interaction (in units $\hbar = m = e = 1$):

$$V = \frac{3(\mathbf{r}_1 \mathbf{R})(\mathbf{r}_2 \mathbf{R})}{R^5} - \frac{\mathbf{r}_1 \mathbf{r}_2}{R^3} \quad (1)$$

(where \mathbf{r}_1 and \mathbf{r}_2 are the radius vectors of the electrons relative to their nuclei), which leads to a cross section for transfer of excitation inversely proportional to the relative collision velocity of the nuclei v . For the collision of identical atoms in the ground s -state and in an excited p -state, this cross section is equal to ⁽⁴⁻⁷⁾:

$$\sigma_1 = 2.26\pi d_{sp}^2/v, \quad (2)$$

where d_{sp} is the dipole moment of the $s - p$ transition.

Let us consider the case in which the characteristic collision frequency v/ρ (where ρ is the impact parameter) is greater than the frequency Ω of the spin-orbit splitting of the p -state. In this case, since (1) does not depend on the spins, the spin may be quantized independently of the orbital angular momentum. This means that during transfer of excitation the directions of the spins of the atomic electrons do not change. Consequently, in a collision of atoms whose electron spins are antiparallel, the transfer of excitation will always lead to the direction of the spin of both the p - and s -states changing to the opposite one. Since the probability of atoms with antiparallel spins meeting is $1/2$, the cross section for change in the spin direction of the ground (and excited) state is

$$\sigma_2 = \frac{1}{2}\sigma_1. \quad (3)$$

3. Let us determine the probability of a change in the hyperfine state of the ground s -state when the direction of the electron spin is reversed. The hyperfine components are characterized by the absolute value of the total atomic spin $F = i \pm 1/2$ (i is the nuclear spin). Since the transfer of excitation depends neither on the electron nor on the nuclear spins, the problem is purely combinatorial in character. The number of all projections of the total spin $F = i + 1/2$ on the quantization axis is equal to $2i + 2$. In two of them (namely, for $M_F = \pm(i - 1/2)$) the probability of transition to the state with $F = i - 1/2$ is equal to $1/4$, while for the remaining M_F it is equal to $1/2$. For $F = i - 1/2$ the probability of transition to $F = i + 1/2$ is equal to $3/4$ for $M_F = \pm(i - 3/2)$, and for the remaining M_F it is equal to $1/2$. Adding the probabilities for each M_F and dividing by the number of all possible M_F , we obtain the transition cross sections:

$$\sigma_2(i+1/2 \rightarrow i-1/2) = \frac{2i+1}{4(i+1)} \frac{1}{2}\sigma_1; \quad \sigma_2(i-1/2 \rightarrow i+1/2) = \frac{2i+1}{4i} \frac{1}{2}\sigma_1. \quad (4)$$

The ratio of these cross sections is equal to the ratio of the numbers of final states.

4. Since the essential impact parameters $\rho \sim v^{-1/2}$, the requirement $v/\rho \gg \Omega$ means

$$v^{3/2} \gg \Omega. \quad (5)$$

For the opposite relation, the fine-structure components of the excited state $P_{3/2}$ and $P_{1/2}$ will pass from one atom to another independently of one another.

Since the interaction is still $\sim R^{-3}$, the dependence of the cross sections (2), (3), and (4) on velocity will remain the same; only the constants in these formulas will change.

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