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The Role of Final State Correlations in Recombination of Atomic Hydrogen

H.T.C. Stoof, L.P.H. de Goey, B.J. Verhaar and W. Glöckle*

Department of Physics, Eindhoven University of Technology,
5600 MB Eindhoven, The Netherlands.

We calculate the rate-constant for recombination in the bulk of a spin-polarized atomic hydrogen gas. We use an exact initial state and include the most essential collision aspects of the final state, except for rearrangement.

The occurrence of three-body dipole recombination in a gas of doubly-polarized atomic hydrogen is at the moment well founded [1] and is furthermore considered to be the main obstacle in reaching the regime where the Bose-Einstein phase transition will take place. Because of the failure of simple models [2] to describe the behavior of the experimental recombination rate, it seems important to perform a highly exact three-body calculation. Apart from the experimental relevance, these calculations are of interest in their own right as an application of the Faddeev formalism [2,3] to atomic physics.

The dipole recombination process can be described very accurately by means of a DWBA-approach, in which the weak electron-electron magnetic dipole interaction V^d is treated in first order. For the transition amplitude f_{fi} this procedure leads to the expression

$$f_{fi} = \frac{\frac{2}{3}m_H}{2\pi\hbar^2}\langle\Psi_f^{(-)}|\sum_{i<j}V_{ij}^d|S\Psi_i^{(+)}\rangle , \qquad (1)$$

where the fully symmetrized initial state $|S\Psi_i^{(+)}\rangle$ and the final atom-molecule state $|\Psi_f^{(-)}\rangle$ obey the three-particle Schrödinger equation, with outgoing and incoming asymptotic boundary conditions, respectively. The corresponding Hamiltonian contains all central (singlet/triplet) interactions between the hydrogen atoms.

Recently we have been able to obtain the initial state by solving the Faddeev equation in momentum space [2,4]. A description using this exact initial state and a final state in which all atom-molecule correlations are absent, turns out to be inadequate to explain the slight decrease of the volume rate constant L_g as a function of magnetic field. Therefore, the conclusion is justified that the final state correlations between the hydrogen atoms are of the utmost importance.

As a first attempt to include these correlations we here present an approach that includes all collision aspects except for rearrangement. During the collision the molecule can be (de)excited and thus change its vibrational and rotational quantumnumbers (denoted by v and ℓ, respectively). Because of the conservation of the total orbital angular momentum L, also the relative angular momentum λ of atom and molecule can change. In this way the problem is reduced to the solution of a two-body coupled channels equation

$$\left\{\frac{\hbar^2}{2\mu}\frac{d^2}{dR^2} + \frac{\lambda(\lambda+1)\hbar^2}{2\mu R^2} + V^{eff}_{v\ell\lambda,v\ell\lambda}(R) - E\right\}\eta_{v\ell\lambda}(R) =$$

$$= -\sum_{v'\ell'\lambda'\neq v\ell\lambda} V^{eff}_{v\ell\lambda,v'\ell'\lambda'}(R)\,\eta_{v'\ell'\lambda'}(R) , \qquad (2)$$

where $\mu=2m_H/3$ is the reduced mass of the atom-molecule system and for each L all channels with $|\ell-L|\leq\lambda\leq\ell+L$ are coupled.

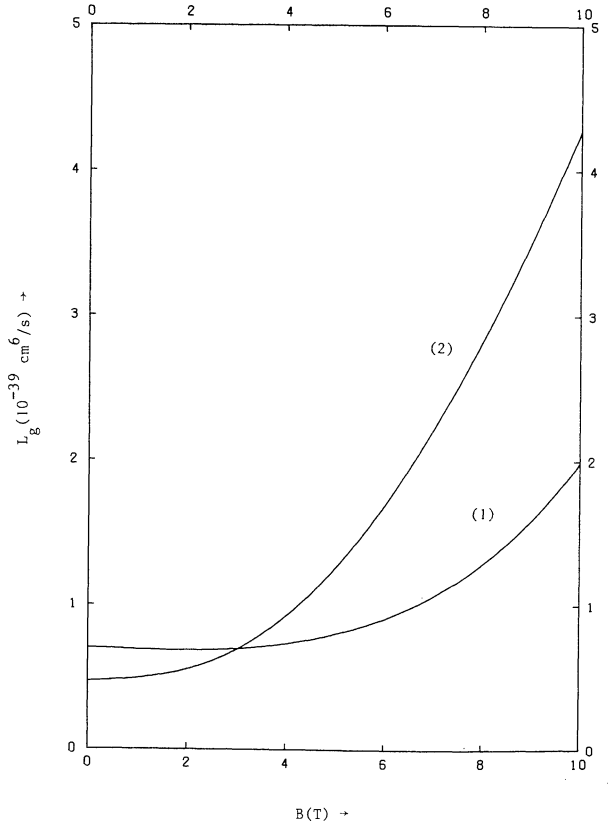

Fig. 1 The volume recombination rate-constant L_g as a function of magnetic field B, with (1) and without (2) final state correlations.

*Institut für Theoretische Physik, Ruhr Universität Bochum, Bochum, West Germany.

We reformulated this equation as a Lippmann-Schwinger equation in momentum space and solved it numerically. It turns out that only the $|\Psi_f^{(-)}\rangle$ states corresponding to ($v=14, \ell=1$) and ($v=14, \ell=3$) outgoing channels contribute significantly to the recombination rate. However, within each of these $|\Psi_f^{(-)}\rangle$ states the coupling to all loosely bound states is important. The results are presented in Fig. 1, in which for comparison also the rate constant in the case of the uncorrelated final state is plotted. Although the magnetic field dependence is now less strong, L_g is still increasing in the experimentally important range of 6-8 T. Furthermore, the magnitude of L_g is roughly a factor of 5 too small in this range. Therefore, we are led to the important conclusion that rearrangement (the dipole-exchange mechanism [2]) is the dominant recombination channel, and thus should be included in any future attempt to give a realistic description of volume dipole recombination. It seems probable that the dipole-exchange mechanisme is also essential to resolve the disagreement with experiment in the case of surface recombination.

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