ɿvestigation of the interaction of 2^3S_1 metastable le atoms with H_2 molecules by the method of ıptical orientation of the atoms

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(Submitted 29 September 1977)
Pis'ma Zh. Eksp. Teor. Fiz. **26**, No. 9, 651–654 (5 November 1977)

Optical orientation of helium atoms was used to investigate the reaction of ionization of molecular hydrogen by 2^3S_1 metastable helium atoms. The temperature dependence of the total ionization cross section is determined in the temperature interval 77–300 K. It is established that this cross section decreases sharply with decreasing temperature.

PACS numbers: 34.50.Hc

The interaction of molecular hydrogen with helium atoms has been attracting increasing ttention of late. The system $He + H_2$ contains a small number of electrons and calculations for this ystem can be carried out quite accurately by various methods. The results of such calculations for ıe case when the helium atom is in the metastable He* state were reported in[1,2]. Owing to the igh excitation energy of He* (19.82 eV and 20.61 eV for the 2^3S_1 and 2^1S_0 states, respectively), the le*–H_2 quasimolecule produced in the collision is unstable to autoionization. The following ɜactions are then possible:

$$He^* + H_2 \rightarrow \begin{cases} He + H_2^+ + e^- & \text{(Penning ionization)} \\ HeH_2^+ + e^- & \text{(associative ionization)} \\ HeH^+ + H + e^- & \text{(ionization with realignment)} \\ He + H + H^+ + e^- & \text{(dissociative ionization)} \end{cases} \qquad (1)$$

The total ionization cross section, which is the sum of the cross sections of all the channels of ɜaction (1), is calculated theoretically in[1,2].

Up to now, the reactions (1) were experimentally investigated by studying the afterglow of ıe reaction products[3] or by using molecular beams.[2] A summary of the experimental data on the ɔtal cross sections for ionization of hydrogen by helium in the 2^3S_1 state at 300 K is presented in[2]. .ccording to[3] the cross section σ_{H_2} is equal to $(1.3\pm0.4)\times10^{-16}$ cm^2 as against $(3.4\pm0.7)\times10^{-16}$ ːn^2 according to[4].This difference between the experimental results is attributed to difficulties in ıe separation of the singlet and triplet channels of the reaction (1) (i.e., reactions with helium in ıe 2^1S_0 and 2^3S_2 states), and also to the need for estimating the degree of deviation of the particle ɜlocity distribution from Maxwellian.

In the present paper the reaction (1) is investigated, for the first time ever, by optical rientation of the helium atoms in the metastable 2^3S_1 state. This method makes it possible to ɜparate in pure form the triplet channel of the reaction (1), as well as to obtain experimental data ɔr low energies of the relative motion of the colliding particles. The reaction (1) was investigated ı the temperature interval 77–300 K.

We used in the experiment the well-known technique of optical orientation of helium atoms in ıe 2^3S_1 state.[5] A weak gas discharge was excited in an absorption chamber filled with a mixture of le^4 (0.36 Torr) and H_2 (0.019 Torr) (at 300 K) and transferred a fraction of the atoms from the round 1^1S_0 state to the metastable 2^3S_1 state. The helium atoms in the 2^3S_1 state were optically

TABLE I. Total cross section for the ionization of the H_2 molecule by helium atoms in the 2^3S_1 state at various temperatures.

T, K	σ_{H_2}, 10^{-16} cm^2
77	0.69 ± 0.10
162	1.11 ± 0.16
220	1.38 ± 0.21
300	1.53 ± 0.23

oriented with the aid of circularly polarized light of wavelength $\lambda = 10\,830$ Å (the $2^3S_1 \to 2^3P$ transition). Magnetic resonance of the optically oriented 2^3S_1 helium atoms was observed. Addition of hydrogen to helium causes decay of the metastable state of the helium atoms as a result of reaction (1). This in turn causes broadening of the resonance line of the 2^3S_1 helium atoms. To separate the contribution due to reaction (1) to the width of resonance line, we determined the width of the magnetic resonance of the 2^3S_1 atoms in pure helium under the same experimental conditions. The ionization cross section σ_{H_2} was determined from the formula

$$\pi \Delta f = N_{H_2} v \sigma_{H_2}. \qquad (2)$$

Here Δf is the contribution made to the width of the resonance line by the reaction (1), and v is the relative velocity for the He–H_2 system.

The experimental investigations were carried out with the installation described in[7].

However, the decay of the metastable state of the helium atoms following addition of hydrogen may be due not only to the reaction (1), but also to collisions with H, H_2^+, H_3^+, HeH^+, etc. Thus, the following reactions are possible with atomic hydrogen:

$$He^* + H \to \begin{cases} He + He^+ + e^- & \text{(Penning ionization)} \\ HeH^+ + e^- & \text{(associative ionization)} \end{cases} \qquad (3)$$

According to[6], the total cross section of reaction (3) is $\sigma_H = 3.3 \times 10^{-15}$ cm^2 (at 300 K). The number N_H of hydrogen atoms under the conditions of our experiment does not exceed 10^{-3} of the number N_{H_2} of the hydrogen molecules, so that $N_H \sigma_H \ll N_{H_2} \sigma_{H_2}$. Consequently, the reaction (3) makes a negligibly small contribution to the width of the resonance line in comparison with the reaction (1).

To obtain an experimental estimate of the contribution of the reaction (3) as well as of the reactions with H_2^+, H_3^+, HeH^+ etc. to the decay of the metastable state of the helium atoms, we determined the width of the resonance line at various discharge intensities. Inasmuch as at low discharge intensity the amount of H, H_2^+, H_3^+, and HeH^+ increases with increasing discharge intensity, one should expect, if these reactions play a noticeable role, a change in the width of the resonance line of the helium atoms with changing discharge intensity. No such change was observed, however, thus confirming the conclusion that these particles play a minor role in the decay of the metastable state of the helium atoms in comparison with H_2.

Thus, the cross section for the ionization of molecular hydrogen pratically coincides with the cross section for the decay of the metastable state of the helium atoms as a result of addition of hydrogen.

Table I lists the ionization cross sections σ_{H_2} obtained from the experimental data with the aid of expression (2). The cross-section error is due to errors in the measurement of the hydrogen pressure and of the resonance-line width, and its average is $\pm 15\%$.

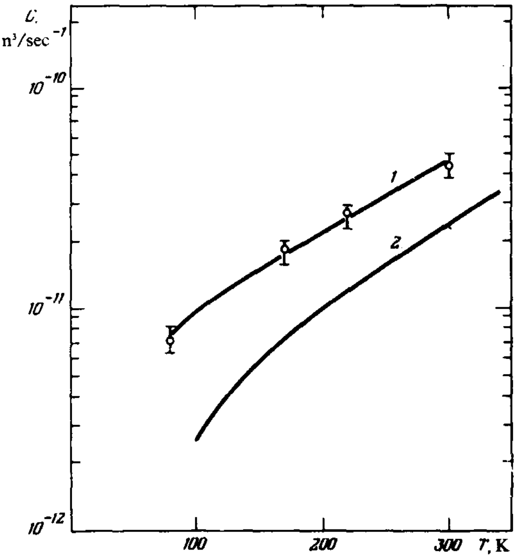

FIG. 1. Temperature dependence of the rate constant of the ionization of H_2 molecules by helium atoms in the 2^3S_1 state: curve 1—experimental values; curve 2—theoretical calculation.[2]

Notice should be taken of the sharp temperature dependence of the ionization cross section: ʼhen the temperature changes from 300 to 77 K the cross section decreases by more than a factor f two. This behavior of the cross section attests to the repulsive character of the potential of the ıteraction between He and H_2 at all the approach distances of the colliding particles. This makes ossible, in particular, optical orientation of the helium atoms at large hydrogen impurity concen- rations by lowering the temperature of the absorption chamber. Thus, at 77 K it was possible to bserve optical orientation and magnetic resonance of the helium atoms in an absorption chamber ontaining 0.36 Torr He^4 and 0.034 Torr H_2.

Figure 1 shows the rate constants $C=\sigma_{H_2}v$ of the reaction (1), otained experimentally in the resent study (curve 1) and calculated theoretically in[2] (curve 2). The experimental dependence grees with the theoretical calculation. The quantitative differences between curves 1 and 2 in the gure are due to the approximate character of the model on which the calculation in[2] is based.

Thus, the method of optical orientation of atoms enabled us to investigate the ionization of the I_2 molecule by only 2^3S_1 metastable atoms of helium, and also to study this process at low energies f the colliding particles.

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