THE PROBLEM OF ELECTRON DETACHMENT FROM H^- IONS IN COLLISIONS WITH INERT GAS ATOMS

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The effective cross sections Q_d were measured for the process of electron detachment from negative ions H^- in single collisions with He, Ne, Ar, Kr, Xe atoms in the ion energy range from 200 to 7000 eV. The results are compared with a theory of the interaction between negative ions and atoms, proposed by Smirnov and Firsov.

SMIRNOV and Firsov [1] proposed a theory of the interaction between negative ions (with a low binding energy of the "excess" electron) and atoms. The theory predicts, in particular, that the cross section Q_d of the process of electron detachment from a negative ion colliding with an inert gas atom should be independent of the negative ion velocity and should be related to the value S of the electron affinity of the atom, from which the negative ion was formed, by the following expression (given in atomic units):

$$Q_d = \pi / k_1 k_2, \qquad k_1^2 = 2S, \tag{1}$$

where $1/k_2$ is the scattering length of an electron on an inert gas atom.[1)] This length is related to the elastic scattering cross section of a very slow electron on an inert gas atom by the formula

$$1 / k_2^2 = Q_{el} / 4\pi. \tag{2}$$

The process of electron detachment from H^- ions in collisions with Ar, Kr, and Xe atoms provides a convenient method for comparing this theoretical prediction with experiment, because the electron affinity energy of the hydrogen atom is well known (S = 0.75 eV).[2] The cross sections of this process were measured by Hasted and Stedeford.[3] However, the curves given in their paper have two separate parts (obtained using different experimental setups) and the energy ranges in which the measurements were carried out did not overlap. In order to join the curve representing the low-energy region with the curve obtained at high energies, it was necessary to assume that the cross section Q_d of the pairs H^- and Ar, H^- and Kr, and H^- and Xe increased very rapidly in the energy range from 2500 to 5000 eV.

The present author measured the cross sections Q_d for the detachment of one electron from H^- ions in single collisions with He, Ne, Ar, Kr, Xe atoms using the same experimental setup in the energy range from 200 to 7000 eV,[2)] which included the energy range not covered by Hasted and Stedeford in [3]. The measurements of Q_d were carried out by recording the slow electrons which appeared when a negative ion beam passed through a collision chamber filled with the gas under investigation. The random error of the measurements amounted to $\pm 3\%$.

For the theory of Smirnov and Firsov [1] to be applicable, it is essential that

$$R_1 = (k_1 k_2)^{-1/2} > r_1 + r_2, \tag{3}$$

where r_1 is the radius of the atom from which the negative ion is formed, and r_2 is the radius of the inert gas atom. Of the investigated pairs, the H^-—Xe pair was the most suitable for comparison with the theory, because the value of $1/k_2$ for Xe was greater than that for Kr or Ar.

Figure 1 shows the experimental curve $Q_d(v)$, obtained by the present author for the H^-—Xe pair. In the investigated range of velocities, the experimentally determined values of Q_d increase with v. (However, the present author did not observe the sharp increase in Q_d at the velocities correspond-

[1)] This formula applies to gases with a positive scattering length.

[2)] The process of detachment of two electrons from the H^- ion in a single collision with a gas atom cannot be important under the experimental conditions employed here. According to the data of Fogel',[4] the cross section for this process in the case of the H^- – Xe pair at 7000 eV energy amounts to 4×10^{-17} cm^2.

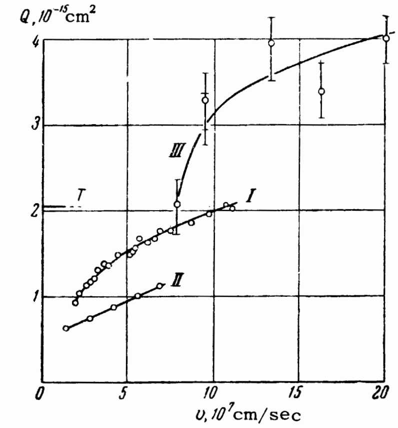

FIG. 1. Effective cross section Q_d for the H^- – Xe pair as a function of the velocity v of H^- ions. Curve I represents the experimental data reported in the present paper. Curves II and III represent the data given in[3].

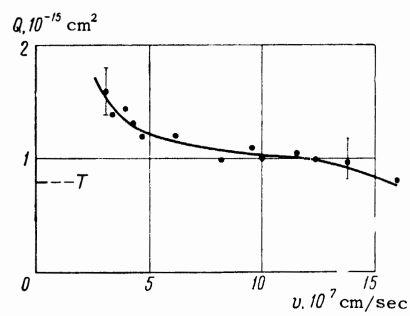

FIG. 2. Effective cross section Q_d for the H^- – H pair according to the data of Fite et al.[7] T represents the theoretical value of Q_d according to [1].

ing to the energies 2500—5000 eV, which was postulated in [3].) The ordinate axis in Fig. 1 shows the value T of the cross section Q_d, calculated on the basis of the Smirnov-Firsov theory using Eqs. (1) and (2) [3)] for S = 0.75 eV. The experimental value of Q_d can be seen to approach the theoretically predicted value at about $v = 10^8$ cm/sec. [4)]

3)For Q_{el}, the value in [6] was assumed (1.16×10^{-14} cm² for Xe).

4)The cross section Q_d for the H^- – H pair was measured by Fite et al.[7] In the range of velocities investigated by them, Q_d decreased and approached closely the value calculated from the Smirnov–Firsov theory for this pair[1] at $v \approx 10^8$ cm/sec (cf. Fig. 2).

v, 10^7 cm/sec	Q_d, 10^{-15} cm²	
	for H^- – Ar	for H^- – Kr
4	0.9	0.9
12	1.5	1.65

For other investigated pairs, the cross sections Q_d, obtained in the investigated range of velocities, also increase monotonically with v. The table lists the values of Q_d (in 10^{-15} cm²) for H^-—Kr and H^-—Ar at the beginning and end of the range of measurements.

According to the Smirnov-Firsov theory, the cross section Q_d should be independent of the velocity and its value should be 5×10^{-16} cm² for the H^-—Ar pair and 1.1×10^{-15} cm² for the H^-—Kr pair. The reason for the discrepancy between experiment and theory may lie not only in the imperfection of the theoretical model, but also in the error of the cross section measurements. Also, the values of Q_{el}, used in the calculations, are not very reliable.

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[1] B. M. Smirnov and O. B. Firsov, JETP **47**, 232 (1964), Soviet Phys. JETP **20**, 156 (1965).

[2] C. L. Pekeris, Phys. Rev. **112**, 1649 (1958).

[3] J. B. H. Stedeford and J. B. Hasted, Proc. Roy. Soc. (London) **A227**, 466, 476 (1955).

[4] Ya. M. Fogel', Dissertation, Khar'kov, 1961.

[5] V. M. Dukel'skiĭ and É. Ya. Zandberg, JETP **21**, 1270 (1951); Yu. F. Bydin and V. M. Dukel'skiĭ, JETP **31**, 569 (1956), Soviet Phys. JETP **4**, 474 (1957).

[6] H. S. W. Massey and E. H. S. Burhop, Electronic and Ionic Impact Phenomena, 1952 (Russ. Transl., IIL, 1958), p. 156.

[7] Hummer, Stebbings, Fite, and Branscomb, Phys. Rev. **119**, 668 (1960).

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143