If we rotate $\vec{E}$ by 45° in the plane of the figure, then we get $H_{c1} = H_{c2}$, and the singularity of the gauss-ampere characteristic will be observed at one value of H. In real many-valley models, the number of singularities is very sensitive to the arrangement of the valleys. Thus, for example, for the arrangement of the valleys in n-Ge, the number of singularities is minimal, namely, one ($\vec{H} \parallel [001]$, $\vec{E} \parallel [100]$), whereas for the valley arrangement in n-Si there are no fewer than two singularities ($\vec{H} \parallel [001]$, $\vec{E} \parallel [110]$). The maximum number of singularities is reached in fields $\vec{E}$ and $\vec{H}$ of a general orientation and is equal to the number of differently oriented valleys, i.e., four in n-Ge and three in n-Si.

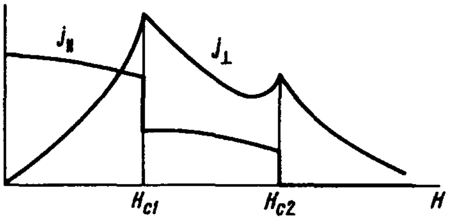

Fig. 2

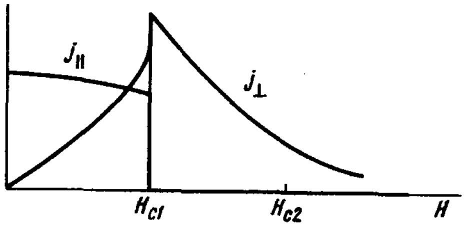

Fig. 3

We proceed now to the case of f-scattering. It is seen from Fig. 1 that in the field interval $H_{c1} < H < H_{c2}$ all the electrons go over to valley 1. Therefore when $H = H_{c1}$, unlike the case of g-scattering, the dissipative current disappears completely, and the Hall current vanishes (Fig. 3). When $H > H_{c2}$, the electrons return to the valley 2, but since all the closed trajectories make the same contribution to the Hall current, the gauss-ampere characteristic has no singularities at $H = H_{c2}$. Thus, the effects under consideration discriminate strongly between intervalley and intravalley scattering.

[1] I. I. Vosilius and I. B. Levinson, Zh. Eksp. Teor. Fiz. 50, 1660 (1966) [Sov. Phys.-JETP 23, 1104 (1966)].
[2] I. I. Vosilius and I. B. Levinson, Zh. Eksp. Teor. Fiz. 52, 1013 (1967) [Sov. Phys.-JETP 25, 672 (1967)].
[3] I. M. Lifshitz and M. I. Kaganov, Usp. Fiz. Nauk 69, 419 (1959) and 78, 411 (1962) Sov. Phys.-Usp. 2, 831 (1960) and 5, 878 (1963)].

ENERGIES OF THE ELECTRONS DETACHED FROM THE NEGATIVE IONS I^-, Br^-, AND Cl^- IN COLLISIONS WITH INERT-GAS ATOMS

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Submitted 23 July 1967
ZhETF Pis'ma 6, No. 9, 857-861 (1 November 1967)

The energy spectra of the electrons that are split off negative ions by collisions with gas atoms have not been experimentally investigated as yet. We have studied in the present work the energy spectra of the electrons that appear when the negative ions I^- (with energies 500 - 2000 eV), Br^- (400 - 1500 eV), and Cl^- (500 - 2700 eV) are disintegrated by collisions with He, Ne, Ar, and Kr atoms.

An electrostatic analyzer, having at its output an electron detector operating in the individual-particle counting mode, was used for an energy analysis of the electrons emitted at angles 90 ± 10° to the direction of the negative-ion beam. Figure 1 shows the plot obtained for the electron energy distribution for the (I^-, He) plane. In addition to a group of slow electrons with energies 2 - 3 eV, the curve shows a distinct peak corresponding to electrons with energies 6 - 7 eV. The second peak appeared at I^- ion energy close to 600 eV, and its height increased with increasing energy of the negative ions I^- (Fig. 2). This peak was observed also in collisions between 1000-eV I^- ions with Ar and Kr atoms. For the (I^-, Ne) pair, at the existing measuring-circuit accuracy and the existing noise level, the peak of the 6 - 7 eV electrons was not observed. It should be noted that in measuring the effective cross sections for the process of electron detachment from the negative I^- ions in collisions with He, Ne, Ar, Kr, and Xe atoms, the value of the cross section for the (I^-, Ne) pair and the form of its plot against the ion energy did not agree with the regularities observed for the other pairs [1].

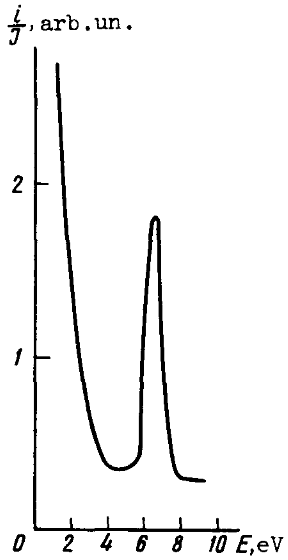


Fig. 1. Energy spectrum of electrons appearing when an electron is detached from a negative ion I^- by collision with He atoms. The ion energy is T = 1000 eV, E - electron energy, i - current in electron detector, I_1 - negative ion current.

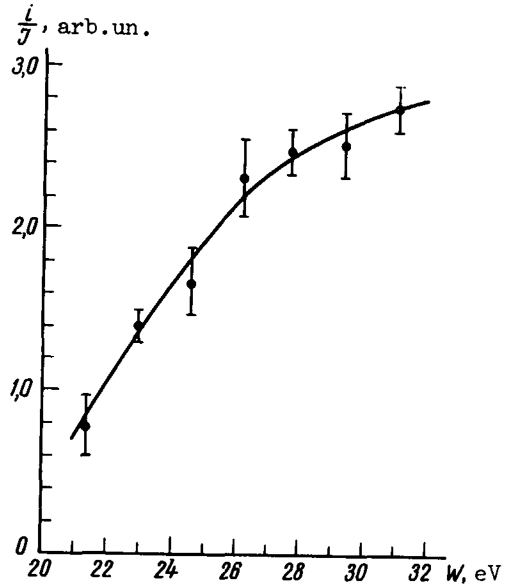


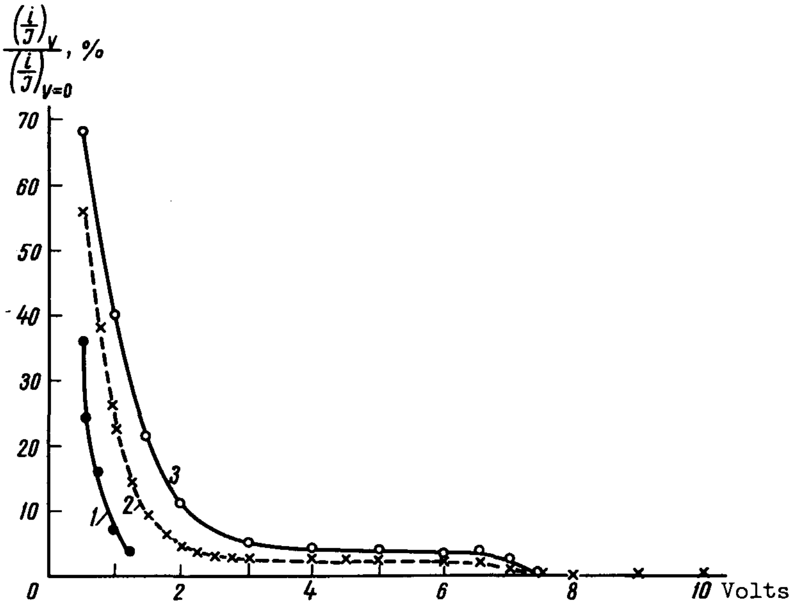
Fig. 2. "Excitation function" of group of 6 - 7 eV electrons; W - kinetic energy of relative motion of I^- and He.

It was possible to replace the electrostatic analyzer in the collision chamber by the system of electrodes used by Lozier [2], which made it possible to plot the energy distribution of the electrons emitted at an angle 90 ± 10° to the beam of the negative ions, using the delaying-potential method. This method yielded delay curves for the electrons ejected from the negative ions by collision with the gas atoms, for I^- paired with He, Ne, Ar, Kr, and Xe, for Br^- we He and Ar, and for Cl^- and Na^- with He.

Figure 3 shows delay curves for the (I^-, He) pair. At I^- ion energies 1000 and 2000 eV, we observed a region of rather steep decrease of the delay curve to V ~ 2 - 3 V, and in the region from 3 to 6 V the delay curve was practically parallel to the abscissa axis.

Such a delay curve confirms independently the existence of two electron groups. Similar curves were obtained for the (I^-, Ar) and (I^-, Kr) pairs at ion energies from 500 to 1000 eV. For I^- in Ne, Br^- in He, Ne, or Ar, Cl^- in He, and Na^- in He, we observed clearly only the electron group with the "low" energies.

Fig. 3. Delay curve for (I^-, He) pair. V - delay voltage. 1 - T = 400 eV, 2 - T = 1000 eV, 3 - T = 2000 eV.



The question of the energy of the electrons that appear during the course of collision of a negative ion with a gas atom was considered by Demkov [3]. According to Demkov's theory, the value of W_E, the number of electrons with energies higher than E, is given by the formula $W_E = W_0 \exp(-\frac{2}{3}\gamma E^{3/2})$, where

$$\gamma \sim \frac{2^{3/2}}{h} V^{-1} \left(\frac{d^2 I}{dR^2}\right)_0^{-1/2} ,$$

and W_0 is the total number of ejected electrons, h Planck's constant, V the velocity of the relative motion of the nuclei of the colliding particles at infinity, R the distance between nuclei, and I the binding energy of the "excess" electron at a given internuclear distance. Starting from these formulas, we can estimate the values of $(d^2I/dR^2)_0$ from the experimental delay curve. In the case of the (Br^-, He) pair such an estimate yielded for $(d^2I/dR^2)_0$ the values (in atomic units) 0.20, 0.24, and 0.29 at T = 1500, 1000, and 500 eV, respectively. Production of electrons with energies up to ~2 - 3 eV can apparently be attributed to the quantum transition of the "excess" electron to the continuous spectrum, a process considered in Demkov's theory. The appearance of the electrons with 6 - 7 eV energy upon detachment of an electron from an I^- ion colliding with He, Ar, or Kr can apparently be explained by assuming the existence of a highly excited state of the I^- ion, which lies in the region of the continuous spectrum. The lifetime of this state is assumed to be larger than the "collision time." The energy released when an electron is detached from a negative I^- ion in this state (its excitation energy after subtracting the electron-affinity energy of the I atom) can be carried away by the escaping electron.

In conclusion, I am deeply grateful to Professor V. M. Dukel'skii for constant attention to this work. I am sincerely indebted to V. I. Ogurtsov and G. M. Mikhailov for help with the work, and to Professor O. B. Firsov, Yu. N. Demkov, B. M. Smirnov, and I. V. Komarov for useful discussions.

[1] Yu. F. Bydin and V. M. Dukel'skii, Zh. Eksp. Teor. Fiz. 31, 569 (1956) [Sov. Phys. JETP 4, 474 (1957)].
[2] W. Lozier, Phys. Rev. 36, 128 (1930).
[3] Yu. N. Demkov, Zh. Eksp. Teor. Fiz. 46, 1127 (1964) [Sov. Phys.-JETP 19, 762 (1964)].

Article by Yu. F. Bydin, Vol. 6, No. 9

On page 298, the last line of the caption of Fig. 1 reads: "I_1 - negative ion current." It should read: "i/I_1 - negative ion current."