ELECTRON CAPTURE CROSS SECTION

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As has been shown by experiment,[2] Gluckstern's[1] calculations of the electron capture cross section σ_3 for singly charged ions of light elements give values which are too high and which decrease too slowly as the ion velocity v is increased. The calculated values are proportional to $v^{-3.5}$, whereas the experimental values for nitrogen ions in nitrogen and argon are proportional to v^{-5}. The calculations are based on classical concepts, which are applicable only when $\kappa = 2iv_0/v \gg 1$, where i is the charge of the ion, and $v_0 = e^2/\hbar$.

For $i \sim 3$ and v/v_0 lying between 3 and 6, when κ is close to unity the method used by Gluckstern becomes inapplicable. In this case σ_3 can be calculated by the statistical method used by Bohr[3] in evaluating the electron capture cross section for fast α particles. The cross section is given in the form of the product $\sigma_1 fn$, where σ_1 is the cross section for the collision process between the ion and electron, in which the electron gains an energy of order $mv^2/2$ (here m is the electron mass), f is the electron capture probability after such a collision, and n is the number of electrons per atom of the substance which participate effectively in the capture. For ions which have a large part of their electron shells, σ_1 is expressed by the same formula, namely $\sigma_1 \sim 4\pi i^2 e^4/(mv^2)^2$, as for α particles only in the case in which the collision diameter $b = 2ie^2/mv^2$ is large enough for the internal structure of the ion to have no effect in its collision with the electron. If b is less than the dimensions of the ion, then σ_1 will be greater due to the increased effective charge. Calculation shows that for that fraction of the ions for which i lies between 0.3 Z and 0.6 Z (here Z is the nuclear charge of the ion) and whose velocities lie between $1.5iv_0/Z^{1/3}$ and $2Z^{2/3}v_0$, the cross section is given by

$$\sigma_1 \sim 4\pi a_0^2 i Z^{1/3} v_0^3 / \sqrt{2}\, v^3,$$

where $a_0 = \hbar^2/me^2$. The maximum binding energy of an electron after capture is given by the ionization potential I of the ion with charge i—1. For $v > u = (2I/m)^{1/2}$, the capture probability f is of the order of $(u/v)^3$. When ions pass through heavy gases, $n \sim Z_2^{1/3} v/v_0$, where Z_2 is the nuclear charge of the atoms in the medium. For ions passing through hydrogen at a velocity not much greater than v_0, we have $n \sim 1$. For nitrogen ions whose charge lies between 2 and 4, for which $u^3 = 0.8 i^2 v_0^3$, the electron capture cross section in argon and nitrogen in the velocity range between $2v_0$ and $5v_0$ is given by the formula

$$\sigma_3 = q \cdot 4\pi a_0^2 i^3 Z_2^{1/3} (v_0/v)^5,$$

where q is a quantity of order unity which takes account of the approximate nature of the calculation. For nitrogen ions passing through hydrogen,

$$\sigma = q \cdot 4\pi a_0^2 i^3 (v_0/v)^6.$$

The dependence of σ_3 on v, i, and Z_2 obtained here is in agreement with the experimental data.[2]

The absolute values of the calculated cross sections lie closest to the experimental ones with $q \approx 2/3$. At lower velocities one should expect the v dependence of σ_3 to be weaker. For $v < u$ and $v < v_0 i/Z^{1/3}$, when $f \sim 1$ and $\sigma_1 \sim 4\pi a_0^2 i^2 (v_0/v)^4$, the cross section σ_3 in heavy gases should be proportional to v^{-3}. The expression for σ_3 in this case agrees with the formula of Bohr and Lindhard[4] up to a constant factor. At high velocities this formula gives values of σ_3 close to those obtained by Gluckstern.

[1] R. L. Gluckstern, Phys. Rev. 98, 1817 (1955).

[2] Nikolaev, Fateeva, Dmitriev, and Teplova, J. Exptl. Theoret. Phys. (U.S.S.R.) 33, 306 (1957); Soviet Phys. JETP 6, 239 (1958).

[3] N. Bohr, Passage of Atomic Particles through Matter, (IIL, 1950). [Probably a translation of Kgl. Danske Videnskab. Selskab. Mat-fysk. Medd. 18, 8 (1948).

[4] N. Bohr, J. Lindgard, Kgl. Danske Videnskab. Selskab. Mat-fysk. Medd. 28, 7 (1954).

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