Bull. Inst. Chem. Res., Kyoto Univ., Vol. 60, No. 2, 1982

NOTE

Effective Charges of Neutral Atoms in Distant Collisions

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Received March 30, 1982

In the classical picture of atom the electronic screening of nuclear charge is depicted as follows; all atomic electrons make their orbital motions many times around the atomic nucleus, so that each orbital electron is regarded as a closed shell with electronic charge surrounding the atomic nucleus. If the observation time is small compared to the periods of orbital motions for some electrons, the screening effect of these electrons are incomplete, and some effective charge should be observed even for a neutral atom.

In the fast collision between a projectile particle and a neutral target atom, where the effective interaction time corresponds to the observation time, this kind of effective charge is expected to reveal itself. When a projectile with veocity $v(=\alpha v_0$, where v_0 is Bohr velocity) pass through straight at the distance $R(=\mathrm{k}a_0$, where a_0 is Bohr radius) from a target atom, the interaction time is given by

$$t=2R/v=2(\mathrm{k}/\alpha)(a_0/v_0). \qquad (1)$$

The period of orbital motion t_i for i-th electron of which orbital radius and velocity are a_i and v_i, respectively, is given by

$$t_i=2\pi a_i/v_i. \qquad (2)$$

The screening is complete if $t>t_i$, and incomplete if $t<t_i$. In the latter case, for simplicity, we assume the screening is such that only t/t_i times of electronic charge is present in the corresponding closed shell. Then, effective charge Z_{eff} of a neutral target atom with atomic number Z_T is expressed as

$$Z_{eff}=Z_T-\sum_i n_i-\sum_j (t/t_j)\,n_j, \qquad (3)$$

where the second term in the right hand side is summed over all orbital electrons with $t>t_i$, and the third term over all orbital electrons with $t<t_j$.

The effective charge Z_{eff} of eq. (3) are calculated with the values of orbital velocities and radii given by Desclaux.[1] The effective charges Z_{eff} are shown in Fig. 1 as a function of k/α for $Z_T=10$, 20, 30, 40 and 50. In this figure, the scales of projectile energies for some collision distances are also given. The present calculation gives the false result that Z_{eff} approaches to Z_T at large projectile energies. However, overall

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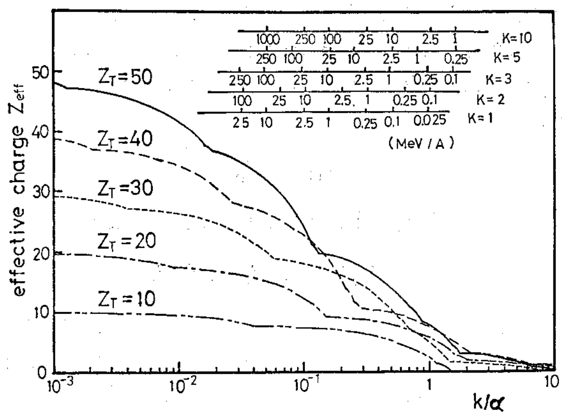

Fig. 1. Effective charges of neutral atoms seen by a fast projectile as a function of parameter k/α, where k is the impact parameter in unit of Bohr radius and α the projectile velocity in unit of Bohr velocity.

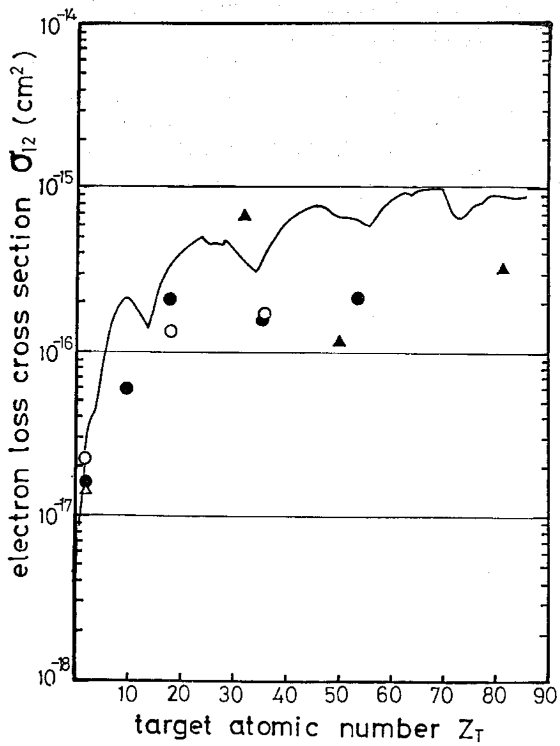

Fig. 2. Electron loss cross sections of 1 MeV He^+ ions for various neutral target atoms. Experimental data are given by Pivovar et al (○, ref. 3 and 4), Itoh et al (△, ref. 5), Kanamori et al (▲, ref. 6) and T. Kido (●, ref. 7).

feature of Z_{eff} gives some clue for investigation of distant collisions with neutral atoms.

As an example of application of this effective charge, the electron loss cross section σ_{12} of 1 MeV He^+ ion for various target atoms are calculated on the basis of binary encounter approximation.[2] The loss cross section is expressed with the maximum ionizable distance R_m,

$$\sigma_{12}=\pi R_m^2. \qquad (4)$$

The distance R_m is determined by solving the following equation,

$$I=2Z_{eff}^2(R_m, v)\, e^4/(m_e v^2 R_m^2), \qquad (5)$$

where m_e is electron mass and I is the ionization energy of He^+. The result is shown in Fig. 2. The calculated cross sections are fairly in good agreement with experimental ones[3~7] with respect to the order of magnitude as well as the trend of increase with Z_T. There is very interesting oscillation with Z_T in the calculated cross sections. Experiments over wide range of target atoms are desired to clarify this oscillation.

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