Stopping power of dicluster hydrogen ion in solid targets

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Abstract:

In this search .the stopping power have been investigated for hydrogen ionic dicluster of atomic number ($z_1=z_2=1$) without damping interacts with (Au, C, Al, and Cs) targets mediums based on an electron gas model. and studying effect of density parameter (r_s)and the internuclear distance (r_{12}) on stopping power. This work of this study show detailed behavior of stopping power of the ionic dicluster of its duality interaction with several electron density targets mediums.

Introduction :

Beams of molecule and cluster ions covering a wide range of energies have become available recently. Such beams are useful tools in fundamental research on the interaction of particles with matter, expanding the number of available degrees of freedom and thus the range of observable phenomena. Moreover, there are promising applications in science and technology. Cluster beams with energies per atom in the KeV or MeV range allow deposition of energy in matter at densities for above that can be achieved with beams of atomic ions [1,2]. This has implications on ion-beam-induced adsorption [3,4], track formation [5], and inertial confinement fusion [6]. Conversely, clusters with energies per atom in the eV regime are of potential use for depositing material because of the highly achievable particle currents that combined with low damage rates [7, 8]. In contrast, when ionized cluster beams are used, the distance between the particles in a given cluster is similar to the interatomic distances in a solid, and therefore the cluster components will interact collectively [8].

This can involve simultaneous interactions between several particles in the cluster and the solid. Hence, the use of cluster beams of atomic ions provides a new tool to investigate dynamical interaction processes in matter [6].

A central quantity representing the interaction of ionized clusters with solid material is the mean energy loss per unit path

length, which is called "Stopping power" (S.P). This quantity is conventionally approximated by the sum of the stopping powers for the constituent atomic ions of the cluster[7],as shown in the equation below:

$$S = \frac{1}{n}\left[\frac{dE}{dx}\right]_{cluster} = \frac{1}{n}\sum\left[\frac{dE}{dx}\right]_{atom}$$

Theoretical side **:**

When implanting atoms in the form of cluster or molecules [9] containing 2-10000 atoms, the implantation energy per atom can be decreased and the beam divergence can be better controlled for low energy implantations. This is important because the semiconductor industry needs

If the ion is moving faster than the fastest target electrons, it loses all its electrons and is completely ionized. These cases are the theoretically best understood ones. An ion moving slowly loses energy only to the free electrons of the target due to momentum exchange with them. Due to the forbidden energy levels, this results in a linear dependence of the stopping on velocity [10]. A high velocity ion can be considered to be a point-like charge, which can collide with all the electrons in the target. The stopping is then inversely proportional to the square of the ion velocity [11].

When the ion velocity is between these two cases, the ion is partially striped leading to a considerably more complicated description [12], because the ion may lose electrons to, and capture them from, the medium.

Theoretical understanding of a cluster impact is more difficult than the ion impacts due to the non linear effects arising from interaction between the cluster atoms [13]. The stopping of cluster of n atoms is not necessarily n times the stopping of one individual ion. The difference is usually called the "vicinage effect". From the electronic stopping point of view, the difference has been explained as originating from the interference in the electronic excitation of the target due to the correlated motion of the

penetrating ion. This has been found to enhance the stopping of cluster in certain conditions [14].

the stopping power of the cluster consist of two terms (single charge interaction S_s and correlated interaction S_{corr})

$$S_{clu} = \left\langle -\frac{dE}{dx} \right\rangle = S_s(\vec{k},\omega) + S_{corr}(\vec{k},\omega) \qquad ...(1)$$

Where

$$S_s(\vec{k},\omega) = \frac{2e^2}{\pi v^2}\int_0^{\infty} \frac{d\vec{k}}{k}\int_0^{\vec{k}.v} \omega d\omega \,\mathrm{Im}\left[\frac{-1}{\in(\vec{k},\omega)}\right](Z_i^2 + Z_j^2) \qquad ...(1a)$$

$$S_{corr}(\vec{k},\omega) = \frac{2e^2}{\pi v^2}\int_0^{\infty} \frac{d\vec{k}}{k}\int_0^{k.v} \omega d\omega \,\mathrm{Im}\left[\frac{-1}{\in(\vec{k},\omega)}\right]\left[(2Z_i Z_j \frac{\sin(kr_{ij})}{kr_{ij}}\right] \qquad ...(1b)$$

Consider a pair of ions z_1, z_2 in correlated motion a structure that may be obtained by the incidence of diatomic molecules with velocity $(\vec{v})$ in a dense medium of valence electrons of solid.

The main electron gas parameters to be used here are the following: Fermi velocity$(\vec{v}_F)$, plasma frequency (ω_p), and Wigner-Seitz radius of the average volume occupied by each electron in units of Bohr radius $a_\circ = \hbar^2/me^2 = 0.529A^\circ$. (with relations: $\vec{v}_F$ = 1.919/r_s, $\omega_p = \sqrt{3/r_s^3}$ in atomic units).

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Calculations & results :

The equation of stopping power of dicluster hydrogen when it's traveling through solid targets can written as the following eq. from sum (1a) and (1b):

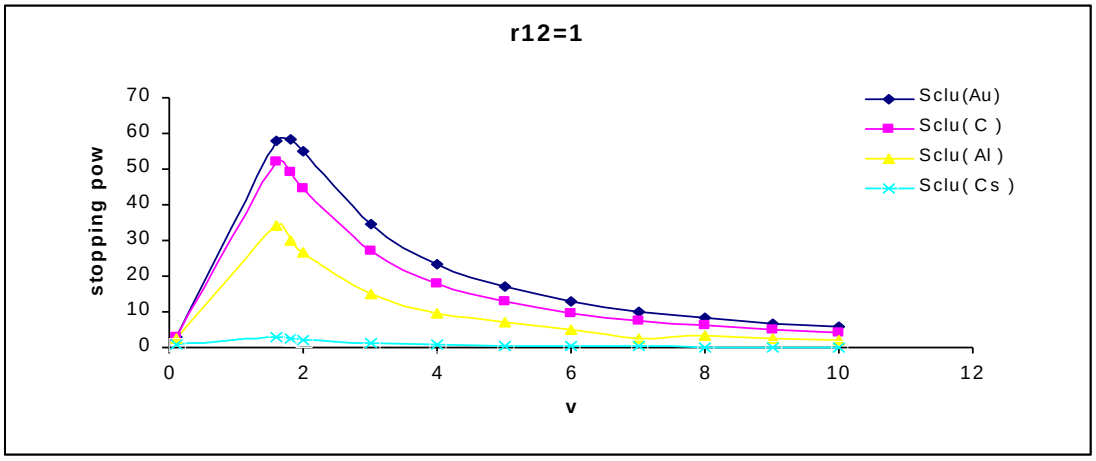
$$Sclu(\vec{k},\omega) = \frac{2e^2}{\pi v^2}\int_0^{\infty} \frac{d\vec{k}}{k}\int_0^{k.v} \omega d\omega \,\mathrm{Im}\left[\frac{-1}{\in(\vec{k},\omega)}\right]\left[(\ (Z_i^2 + Z_j^2) + 2Z_i Z_j \frac{\sin(kr_{ij})}{kr_{ij}}\right] \qquad ...(2)$$

The terms have separated with i=j, which give the energy loss of totally independent charges, and the terms with $i \neq j$, which represent interference effects on the energy loss due to the simultaneous perturbation of the medium by the charges in correlated motion.

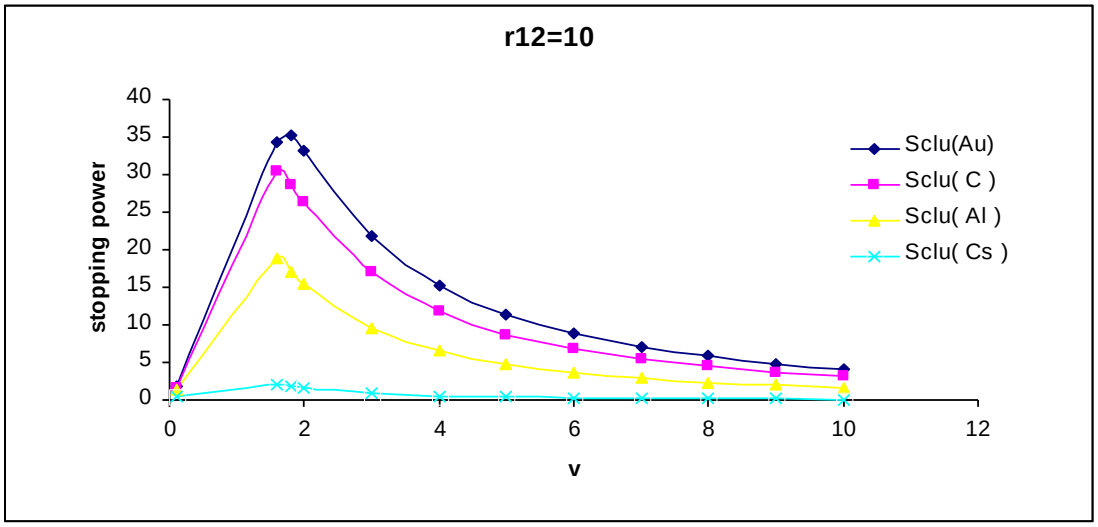
Eq. (2) is a general formula for the stopping power of the dicluster of charges (z_1) and (z_2) then

$$Sclu(\vec{k},\omega) = \frac{2e^2}{\pi v^2}\int_0^{\infty}\frac{d\vec{k}}{k}\int_0^{k.v}\omega d\omega \,\mathrm{Im}\left[\frac{-1}{\in(\vec{k},\omega)}\right]\left[\left(Z_1^2+Z_2^2\right)+2Z_1Z_2\,\frac{\sin(kr_{12})}{kr_{12}}\right] \quad ...(3)$$

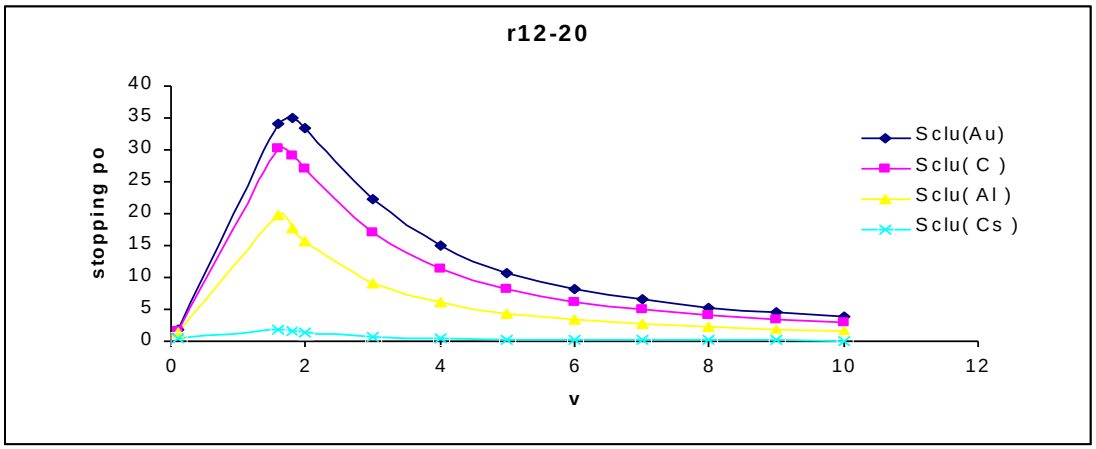
By using random phase approximation at low velocities and plasma pole approximation at high velocities and after programming this equation we got figure (1) which show stopping power versus velocity of cluster of (Au,C,Al,Cs) targets. We note that the first target (Au) take highest value while the final target (Cs) take lowest value and we note when value of internuclear distance (r_{12}) become bigger that's not effect on stopping power. thus we can show relationship between stopping power of (Au) and (v) and (r_{12}) in 3diamention as fig (2).while fig(3) shows stopping power versus velocity (v) and density parameter (r_s).



(a)

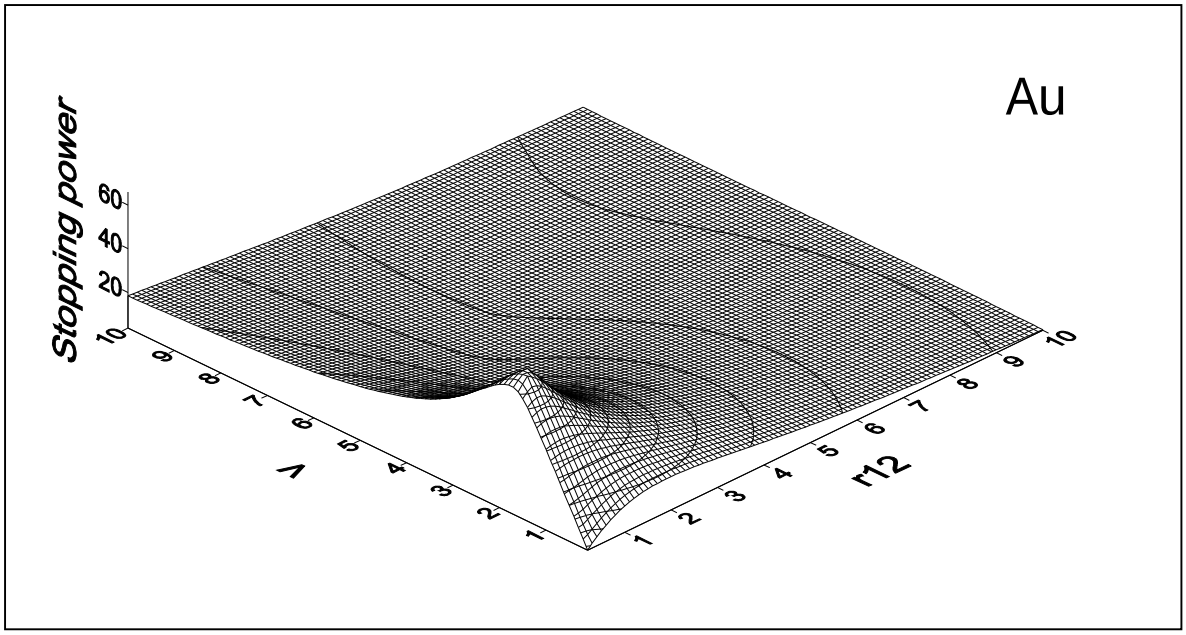


(b)

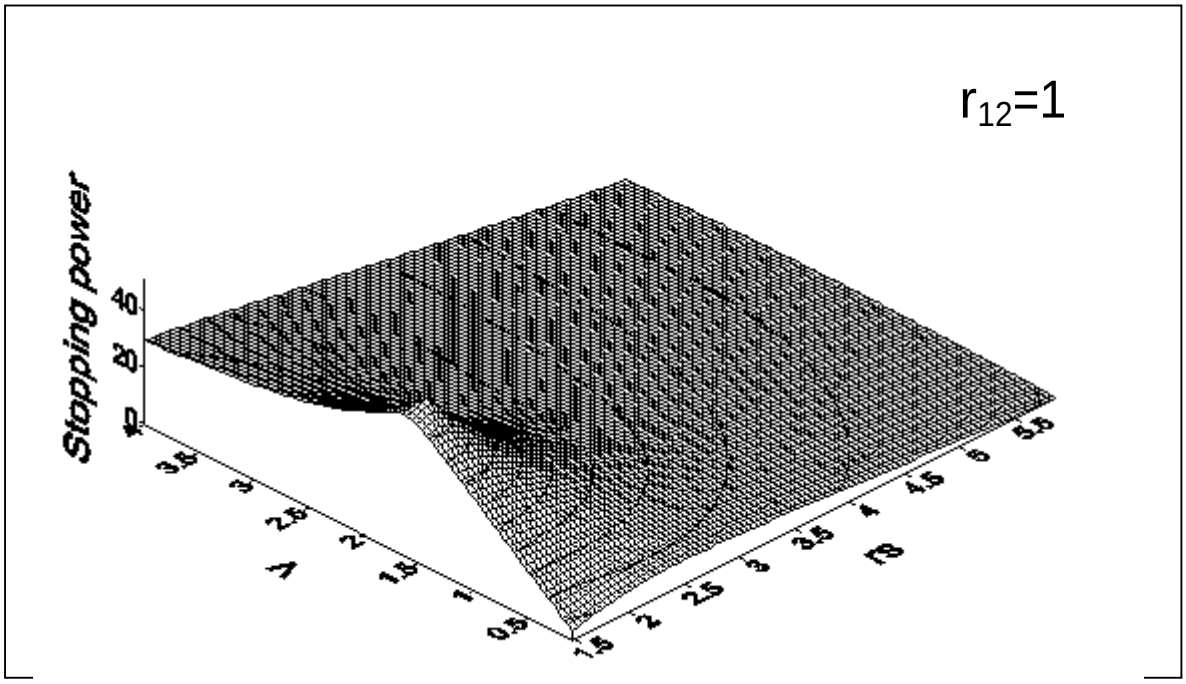


(c)

Fig (1): Show the stopping power of (Au , C , Al , Cs) targets when a) r_{12} =1, b) r_{12} =10 , c) r_{12} =20



Fig(2) Show stopping power of (Au) target versus velocity and internuclear distance



Fig(3) Show stopping power versus velocity and density parameter

Conclusions:

When swift clusters impinge on a solid target their binding electrons are stripped of after traversing the first atomic layers[14], forming then a cluster of atomic ions, these ions interact with the target and also among them (under the influence of Coulomb forces). The correlated motion of the cluster partners produces the so called vicinage effects , which are satisfactorily evaluated within the dielectric formalism of the stopping power[15]. Within this formwork, each cluster constituent is treated as a point like charge, and the target is modeled as an isotropic and homogenous electron gas, whose response to an external perturbation is characterized completely by its dielectric function $\in(k,\omega)$, where k and ω are, respectively, the momentum and the energy transferred to electronic excitations in the medium.

in this work we note behavior stopping power versus projectile velocity don't effect of density parameter or wigner-seitz radius (r_s) and internuclear distance (r_{12}) but it's value decrease with increase (r_s). The increasing values of r_s leads to decrease $\vec{v}_F$ (Fermi Velocity) of a target and also the density of electrons according to the relation as $\vec{r}_s = \left(\frac{3}{4\pi n_e}\right)^{1/3}$, where r_s is the radius of a sphere contains one electron [16] and *n* is the density of electrons. The impingement of dicluster in a target of small r_s means that there will be high dense of electrons to screen the projectile and retarding it. In addition, one may expect a short interaction time, therefore each target medium exhibits prevention against the projectile dependant on its density where $Au(r_s = 1.49)$ represents the highest screening and then $C(r_s = 1.66)$, $Al(r_s = 2.12)$ and $C_s(r_s = 5.88)$ .so the value of stopping power decrease with increase (r_{12}) and its take constant value when (r_{12})take value bigger.

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الخلاصة:-

في هذا البحث. بُحثت قدرة الإيقاف لعناقيد الهيدروجينية الأيونية الثنائية للأعداد الذرية ($z_1=z_2=1$) بدون اضمحلال تتفاعل مع الأهداف صلبة (Au ,C ,Al , Cs) بالاعتماد على نموذج الغاز الالكتروني . ودراسة تأثير مؤثر الكثافة (r_s) والمسافة النووية (r_{12}) على قدرة الإيقاف . هذا العمل يعطي دراسة تفصيلية لسلوك قدرة الإيقاف للعنقود الأيوني الثنائية لتفاعله المزدوج مع عدة أوساط ذات كثافة الكترونية مختلفة.