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Energy Loss of Swift heavy Ions in Solids

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ABSTRACT: Energy loss of swift heavy ions is important not only to understand the basic ion-matter interaction process but also required in many scientific applications, where swift heavy ions are used. The energy loss for swift heavy ions covering Z=3-20 (0.1-5.0MeV/n) has been calculated in the elemental absorbers Ni, Ag and Au. The present calculations have been made by involving a new approach for effective charge parameterization which is major input parameter in the energy loss calculations. A close agreement between these calculated and experimental measured value has been observed.

Keywords: Energy loss; swift heavy ions; effective charge; ionization potential.

INTRODUCTION: The accurate knowledge of heavy ion stopping power in different material is of the interest from both fundamental and practical point of view. In the interaction between the swift heavy ion and the matter, average energy loss per unit path length play an important role in the many fields such as ion beam based analytical technique like Rutherford Back Scattering (RBS), Elastic Recoil Detection Analysis (ERDA), Nuclear Reaction Analysis (NRA), Particle Induced X-Ray Emission (PIXE) etc. With the increasing use of ion beam in material science and in nuclear physics experiments, it is essential to know the correct stopping power value for correct interpretation of data. Practically, it is not possible to measure stopping power values for a large number of ion-target combinations, employed in various experiments, because the number of such combination is very large. Therefore we rely on the various existing formulations [1-6] which are based on empirical/semi-empirical parameterization of effective charge, which is major input parameter in these formulations. In our earlier studies, we tried to develop the effective charge parameterization without resorting to empirical or semi empirical formulation which could provide a good agreement with the experimental data for ions Z=3-29 in the light targets like C, Al etc [7].

In the present study, the stopping power calculated for swift heavy ion covering Z=3-20 in elemental solids like Ni, Ag and Au in the energy range 0.1-5.0 MeV/n have been performed. After comparison, significant larger deviations were noticed. Therefore our approach was modified suitably for extension to heavy targets.

Theoretical Calculations: The present calculations are based on the Bohr's approach [8] which is applicable at all energies unlike Bethe [9] and Bohr's [10] which is applicable at high and low energies respectively, with χ=2Z*vo/v, where Z*,vo and v are the eff. Charge , Bohr's velocity and ion velocity respectively.

$$-\frac{dE}{dX}=\frac{2\pi Z^{*2}e^4N}{mv^2}\left[\sum_i \ln\left(\eta_i^2[\chi]^{-2}\right)+\sum_i \ln\left(\eta_i^2\left[\frac{\chi}{\eta_i}\right]^{-1}\right)\right] \quad (1)$$

where η_i= 2v/ui, with u_i as the orbital velocity of i^th electron of the target atom and N is the number of target atoms per unit volume. We developed an approach for effective charge parameterization which is a major input parameter in energy loss calculations without any empirical/semi-empirical parameterization.

Calculation of u_i: The orbital velocity u_i of the i^th electron of the target atom is related to the I_i (successive ionization energies) through the relation $I_i=\frac{mu_i^2}{2}$ where m is the mass of electron. The value of u_i is calculated after modified the value of I_i using the Sternheimer's approach [11-12].

Effective charge calculations: When a projectile ion of high velocity enters in the target medium it loss all its electrons, so in this situation the charge on the incident ion is same as the nuclear charge. As the ion passage through the medium its velocity starts reduces and when its velocity comparable to the velocity of k-shell electrons then it starts capturing of electrons gradually. As velocity of ion further reduces, it captures more and more electrons. Under this situation, the effective charge is related to total nuclear charge through the relation

$$Z^* = Z - S \qquad (2)$$

where S is the combined shielding effect of all inner electrons which is the sum of individual shielding contribution by various electrons. This shielding effect is calculated by Slater or clement and Raimondi rules by taking into account the extent of capture. Thus the effective charge Z^* is determined by equation (2).After substituting the values of Z^* and u_i in equation (1), the energy loss rate can be determined.

These calculated energy loss values are not compatible with the experimental data for heavy targets like Ni, Ag and Au. Therefore some fitted parameters in our calculations for the effective charge are deduced and employed in the present calculations. A close agreement has now been noticed within the experimental and calculated values.

RESULTS AND DISCUSSION: As a suitable mean of estimating the accuracy of present approach, we have compared the calculated values of energy loss rate with the experimental data as available in literature [13-21]. Such a comparison for projectiles Z=3-20 in the elemental absorbers Ni, Ag and Au has been presented in the Figures 1 -3, respectively. These Figures clearly indicate that a close agreement between the calculated and experimental values.

CONCLUSIONS: The stopping power for the ions Z=3-20 in elemental solids like Ni, Ag and Au calculated using the effective charge parameterization without any empirical semi empirical parameterization after modifying minor fitted parameters provided the close agreement with the experimental values.

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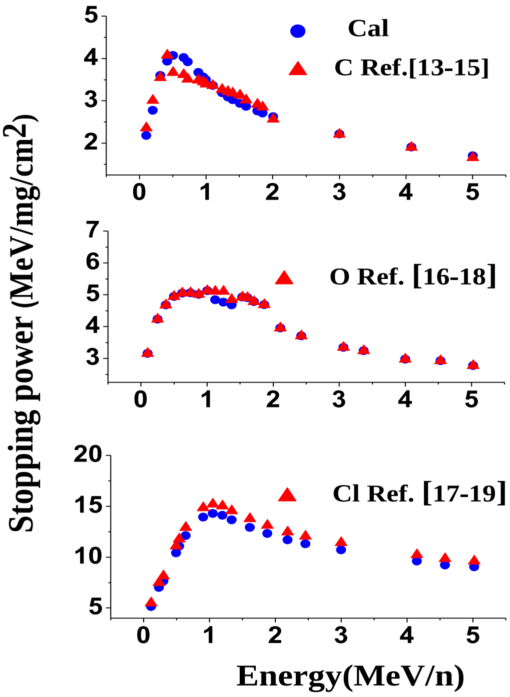

Figure 1: Comparison of experimental stopping power values with the results of our calculations for C, O and Cl projectiles in Ni absorber

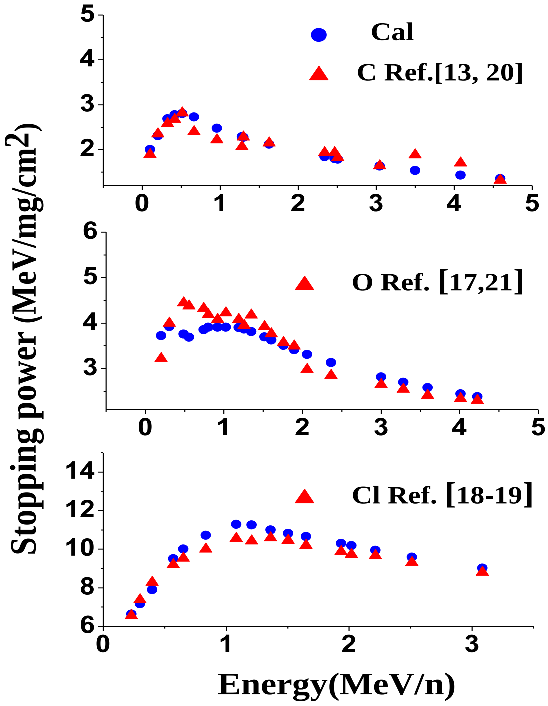

Figure 2: Comparison of experimental stopping power values with the results of our calculations for C, O and Cl projectiles in Ag absorber

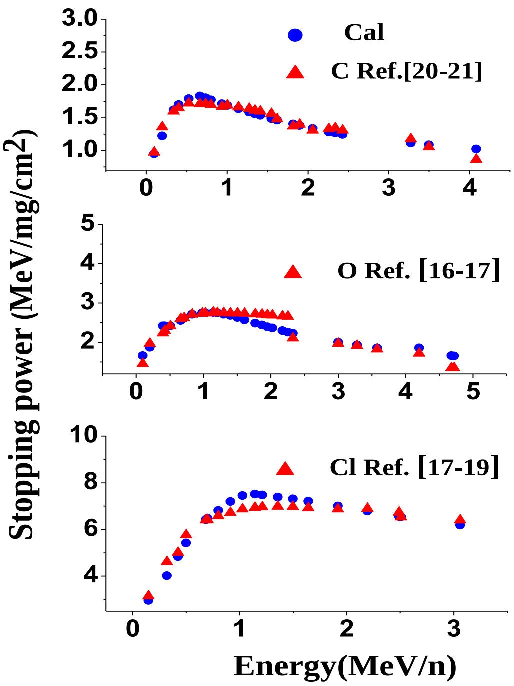

Figure 3: Comparison of experimental stopping power values with the results of our calculations for C, O and Cl projectiles in Au absorber

REFERENCES:

1. Northcliffe L.C. and Schilling R.F. (1970), "Range and stopping power tables for heavy ions" *Atomic Data and Nuclear Data Tables A*, 7, 233-463.
2. Paul H. and Schinner A. (2002), "An empirical approach to the stopping power of solids and gases for ions from $_{3}$Li to $_{18}$Ar- Part II" *Nucl. Instrum Methods in Phys. Res. B*, 195, 166-174.
3. Ziegler J.F.(2008), *Computer Code SRIM* 05, Available from: http://www.srim.org/.
4. Sigmund P. and Schinner A. (2002), "Binary theory of electronic stopping" *Nucl. Instrum. Methods Phys. Res.B*, 195, 64-90.
5. Hubert F., Bimbot R. and Gauvin H.(1990), "Range and stopping power tables for 2.5-500 MeV/Nucleon heavy ions in solids" *Atomic Data and Nuclear Data Tables*, 46, 1-215.
6. Diwan P.K., Sharma A. and Kumar S. (2001), "Stopping power for heavy ions (3≤Z≤35) in solids at energies ~0.5 - 2.5 MeV/n" *Nucl. Instrum. Meth. Phys. Res. B*, 174, 267-273.
7. Rani B., Sharma K., Neetu, Anupam, Kumar S. and Wirk H.S. (2015), "Energy Loss for Swift Heavy Ions in Different Elemental Absorbers: A Different Approach for Effective Charge Parameterization" *Solid State Phenomenon*, 238, 196-205.
8. Bohr N. (1948), "The penetration of atomic particles through matter" *Mat. Fys. Medd. K.Dan. Vidensk. Selsk*, 18, 1-144.
9. Bohr N. (1913), "On the theory of the decrease of velocity of moving electrified particles on passing through matter" *Phil. Mag*., 25, 10-15.
10. Bethe H. (1930), "Theory of the passage of rapid corpuscular rays through matter" *Ann. Phys.*, 5, 325-400.
11. Sternheimer R.M. (1952), "The density effect for the ionization loss in various materials" *Phys. Rev*., 88, 851-859.
12. Sternheimer R.M. (1956), "Density effect for the ionization loss in various materials" *Phys. Rev.*, 103, 511-515.
13. Santry D. C. and Werner R. D. (1991), " Measured stopping powers of 12C and 14N ions in thin elemental foils" *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, 53, 7-14.
14. Rauhala E. and Räisänen J. (1988), "Stopping powers and energy loss of 3–22-MeV C 12 ions in Havar, nickel, Kapton, and Mylar" *Physical Review B*, 37 (16), 9249.
15. Rauhala E. and Räisänen J. (1990), " Stopping powers of Li 7, B 11, C 12, N 14, and O 16 ions in C 16 H 14 O 3 polycarbonate" *Physical Review B*, 42 (7), 3877.
16. Santry D. C. and Werner R. D. (1992), " Measured stopping powers of 16O and 19F ions in thin elemental films" *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atom*, 69, 167-173.
17. Ward D., Graham R. L. and Geiger J. S. (1972), "Measurement of Stopping Powers for 4He, 16O, and 35Cl ions at 1 to 3 MeV per Nucleon in Ni, Ge, Y, Ag, and Au" *Canadian Journal of Physics*, 50, 2302-2312.
18. Booth W. and Grant I. S. (1965), "The energy loss of oxygen and chlorine ions in solids" *Nuclear Physics*, 63, 481-495.
19. Forster J. S., Ward D., Andrews H.R., Ball G.C., Costa G. J., Davies W. G. and Mitchell I. V. (1976), " Stopping power measurement for 19F, 24Mg, 27Al, 32S and 35Cl at energies~ 0.2 to~ 3.5 MeV/nucleon in Ti, Fe, Ni, Cu, Ag and Au" *Nuclear Instruments and Method*, 136, 349-359.
20. Abdesselam M., Stoquert J.P., Guillaume G., Hage-Ali M., Grob J.J. and Siffert P. (1991), "Stopping power of C and Al ions in solids" *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, 61, 385-393.
21. Porat D. I. and Ramavataram K. (1960), "A Proposed Method for Measuring Ranges of Heavy Ions in Solids" *Proceedings of the Physical Society*, 76, 438-445.