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The Range of Heavy Ions in Compounds at Low Velocity $v \leq v_0 Z^{2/3}$

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Abstract: *The range of heavy ions in compounds is fitted with power equation form which gaves good agreement with previous work of SRIM[13] by Ziegler taking in the consideration effective charge and nuclear stopping cross-section (i) from Lindhard and (ii) from Sorensen. The coefficients of range have been calculated numerically using least square method [LSM]. Through the investigation of present work, especially when taking the effective charge in the consideration the stopping cross-section is not directly proportional to the velocity at as presented by Lindhard has different form of curvature according to previous experimental data. Good agreement achieved with previous work of software SRIM presented by Ziegler [13]. More work needs to do with the range of heavy ions in compounds.*

Keywords: *Stopping power, low-velocity stopping, Range.*

1. INTRODUCTION

Research on the penetration of heavy ions in matter it's the studies of the scattering and the stopping of fission fragments [1]. The subject received renewed interest in the application of accelerators in the study of atomic collisions and material properties [2, 3], ion implantation[4], ion-beam modification [5], ion-beam analysis [6,7] and ion-beam therapy [8].While the penetration of protons and alpha particles is well described by Bethe's [9] theory of the stopping of point charges over a wide range of beam energies, penetration theory for heavier particles increases in complexity with increasing atomic number Z_1 for several reasons: The Coulomb force is not necessarily a weak perturbation, the projectile cannot necessarily be treated as a point charge, and energy may be lost in charge-changing collisions. The range of heavy ions of low velocity, and their connection to the basic problem of quasi-elastic collisions between ions and atoms. Three characteristic features give rise to complications [10]. First, both electronic and nuclear stopping must be studied thoroughly, because they are similar in magnitude. Second, because of the frequent large deflections of the ions one must distinguish carefully between various range concepts. Third, the variety of choice of atomic number of both ion and substance gives an additional difficulty.

2. THEORY

The total range of the swift particle may be observed in track detectors like photographic emulsion. The observation of many tracks can then give the probability distribution in the total range in this kind of calculated observed range dependent on the energy loss only, and not on scattering of the particle [11]. To compute total path length in medium where the initial energy E_0arrived to rest stat E=0 can be using:

$$R = -\int_0^{E_0} \left(\frac{dE}{dx}\right)^{-1} dE \quad (1)$$

Where:

R: Range of charge particle

dE/dx : Stopping power for charge particle

According to the Eq. (1), and because we are working in low relative velocity region, $v \leq v_0 Z_1^{3/2}$, can be substitute the stopping power by lindhard or Bohr formula or assume a fitting equation as follows:

Let $R = \alpha E^{\beta}$ (2)

Whereα, β are fitting parameters, differential Eq. (2) with respect to energy,

Eq. (2) can be derivative to getting

$$\frac{dR}{dE} = \alpha\beta E^{\beta-1} \tag{3}$$

Taking logarithm on both sides of eq. (3)

$$\ln\left(\frac{dE}{dR}\right) = -\ln(\alpha\beta) + (1-\beta)lnE \tag{4}$$

Where $\frac{dE}{dR}$ given in Eq. (4) can be given as follows:

$$\frac{dE}{dR} = \left(\frac{dE}{dR}\right)_e + \left(\frac{dE}{dR}\right)_n = N_a(S_e + S_n) \tag{5}$$

$\left(\frac{dE}{dR}\right)_e$ is the electronic stopping cross-section given by Lindhard [12], $\left(\frac{dE}{dR}\right)_n$ is the nuclear stopping cross-section given either by Lindhard or Sorenson.

Eq. (4) equivalent to straight equation:

$$y = A + bx \tag{6}$$

Where

$$y = ln\left(\frac{dE}{dR}\right) \tag{7}$$

$$A = -\ln(\alpha\beta) \tag{8}$$

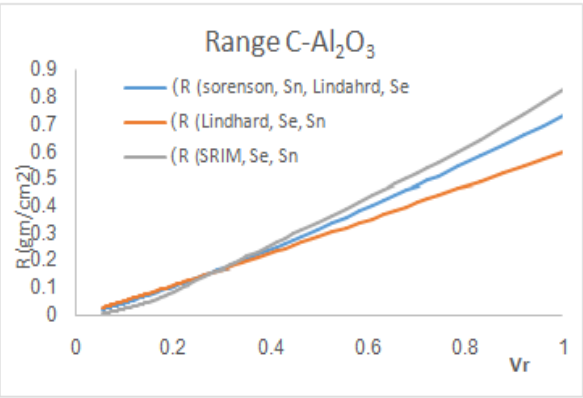
$$B = (1-\beta); \qquad \beta = 1 - B \tag{9}$$

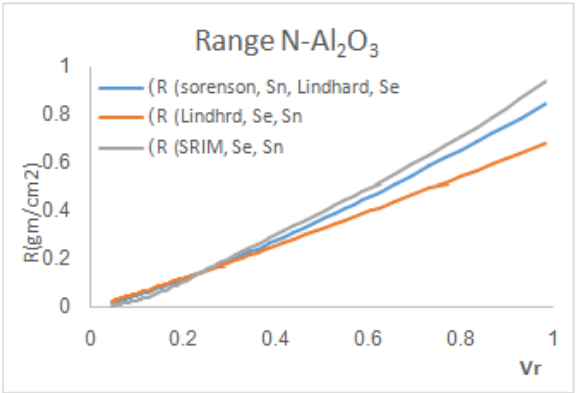
$$X = lnE \tag{10}$$

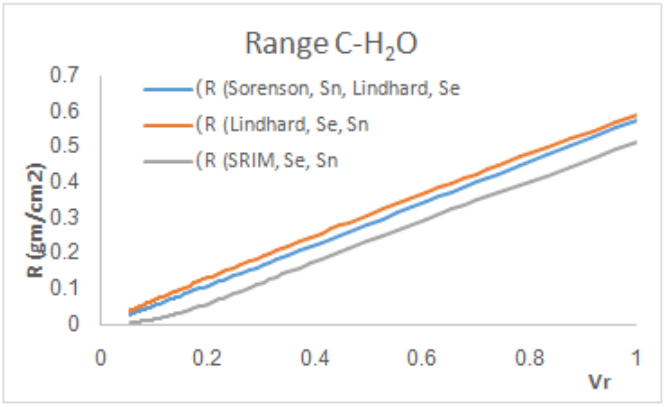
The parameter α and β have been found them numerically where using Least Square Method (LSM). Table (1) shows the parameters α in (gm/cm^2) and β for O, N, C-ions in compounds Al_2O_3, ZrO_2, H_2O and C_6H_6.

Table (1) shows the parameter α and β for Oxygen, O, in (Al2O3, ZrO2, H_2O and C_6H_6) with nuclear stopping cross-section, S_n given by Lindhard and Sorenson.

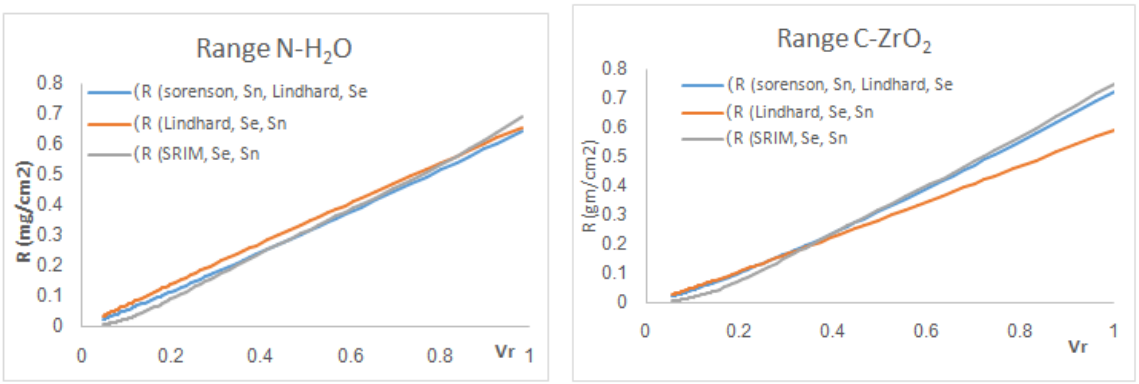
N	*Incident ions*	*Targets*				
			β	*α (gm/cm²)*	*β*	*α (gm/cm²)*
1	O	Al2O3	0.5906	5.3565	0.6832	3.7305
2		ZrO2	0.9009	4.9521	1.0514	0.396
3		H2O	0.5205	1.1311	0.5896	0.9905
4		C6H6	0.9055	5.0036	1.0559	3.4301
5	N	Al2O3	0.3266	26.9637	0.3685	23.9304
6		ZrO2	0.8759	5.8441	1.0372	4.1511
7		H2O	0.3518	29.0573	0.3956	25.868
8		C6H6	0.6343	3.4142	0.8275	2.4056
9	C	Al2O3	0.5906	5.3565	0.6832	4.7305
10		ZrO2	0.8184	6.3772	0.9894	4.726
11		H2O	0.7956	4.8109	0.9509	3.7575
12		C6H6	0.9078	8.5449	1.0799	6.1648

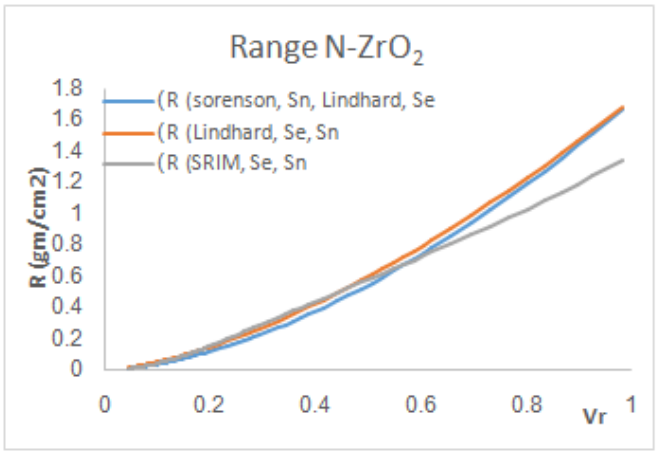




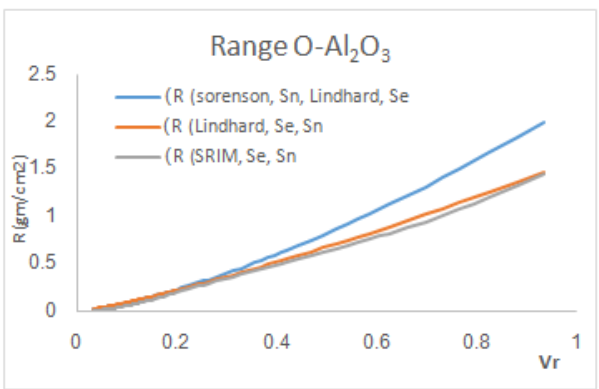


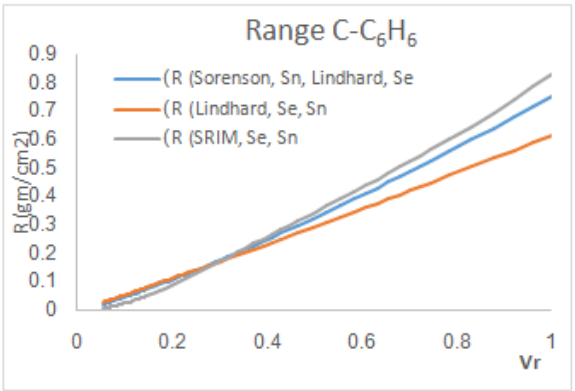
Fig(1-1). *The range R in (gm/cm^2) calculated by taking (i) S_e from Lindhard, S_n from Sorenson, (ii) S_e and S_n from Lindhard, (iii) SRIM-output for C-ion in Al_2O_3, H_2O and ZrO_2*

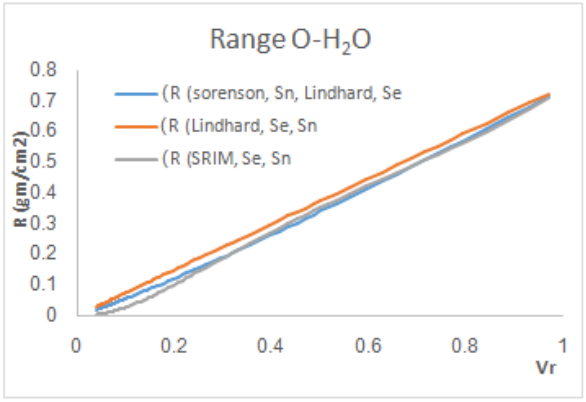




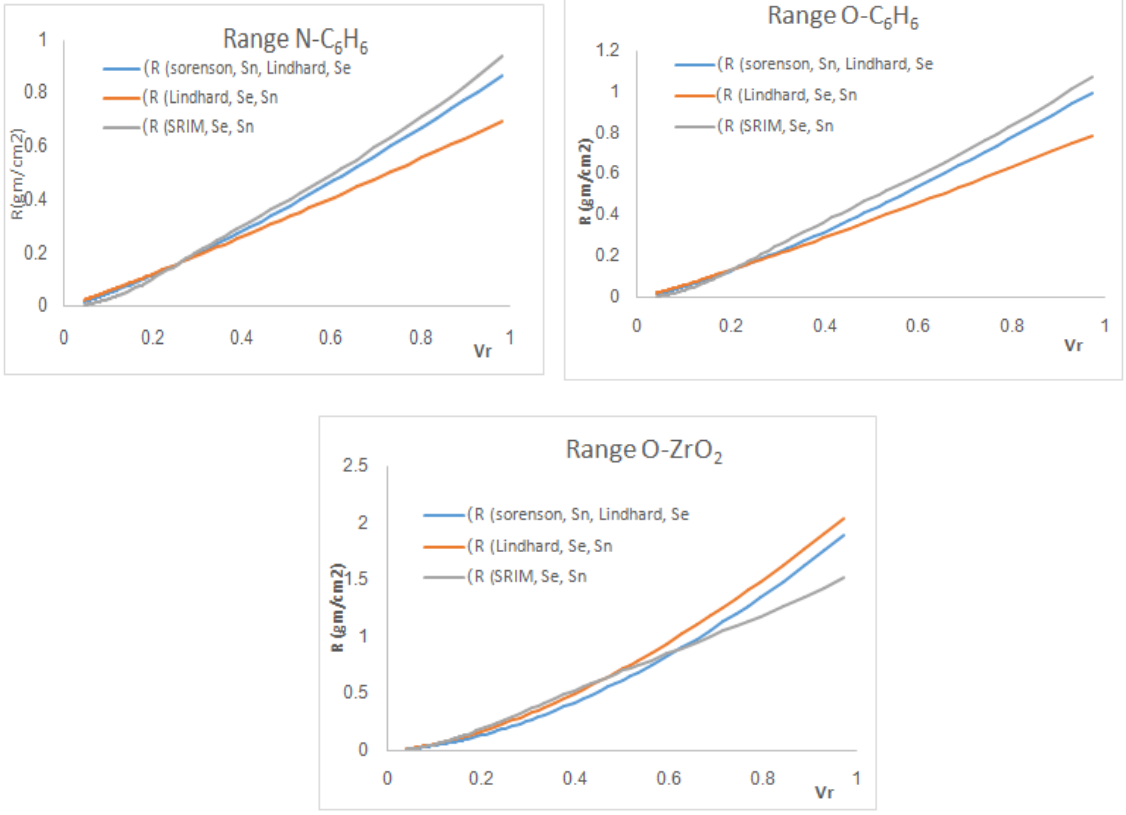
Fig(1-2). *The range R in (gm/cm^2) calculated by taking (i) S_e from Lindhard, S_n from Sorenson, (ii) S_e and S_n from Lindhard, (iii) SRIM-output for N-ion in Al_2O_3, H_2O and ZrO_2.*







Fig(1-3). *The range R in (gm/cm^2) calculated by taking (i) S_e from Lindhard, S_n from Sorenson, (ii) S_e and S_n from Lindhard, (iii) SRIM-output for O-ion in Al_2O_3, H_2O and ZrO_2*



Fig(1-4). *The range R in (gm/cm^2) calculated by taking (i) S_e from Lindhard, S_n from Sorenson, (ii) S_e and S_n from Lindhard, (iii) SRIM-output for N, C, O, in C_6H_6.*

3. Result and Discussion

Figs. (1-1,1-4) show the range with ions velocity, $v \leq v_0 Z_1^{3/2}$ for The incident ion O, N, C, in liquid water, H_2O, Aluminum Oxides, Al_2O_3, Zirconium Oxides, ZrO_2 and C_6H_6, Benzene Compounds. At low velocity the range of the incident ions increasing when increasing relative velocity and can be notes Lindhard's result is straight line this refer to the strong relation between range and velocity. The range, R in (gm/cm^2)has been calculated: (i) the electronic stopping cross-section S_e from Lindhard and nuclear, S_n from Sorenson, (ii) S_e and S_n are taken from Lindhard. The other value of range has been taken from SRIM as shown in fig. Good agreement is achieved with previous work of SRIM[13] output.

4. Conclusion

The range, $R\,(gm/cm^2)$ of heavy ions in compounds shown in Figs. (1-1) and calculated numerically, taking in the consideration electronic and nuclear collision. The results show that range

working well in power form given in Eq. (2). The other way to run Eq. (2) on each element of compound then apply Bragg's rule to get range in compound.

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