Research Journal of Recent Sciences _____ ISSN 2277-2502
Vol. **1(6),** 70-76, June **(2012)** *Res.J.Recent Sci.*

Review Paper

Continuous Slowing Down Approximation (CS and DA) Ranges of Electrons and Positrons for Carbon, Aluminium and Copper

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Available online at: www.isca.in
(Received 22nd February 2012, revised 16th March 2012, accepted 3rd April 2012)

Abstract

In this paper we present a relation for continuous slowing down approximation (CSDA) ranges for electrons and positrons of Carbon, Aluminium and Copper in terms of energy from 700 keV to 50000 keV and have been fitted by a second order polynomial approximation with two parameters. These parameters depend upon the atomic weight (A) and atomic number (Z) of the absorber. It has been found that the polynomial potential function gives better agreement with the available experimental data.

Keywords: CSDA ranges, intermediate energy range, atomic number, atomic weight.

Introduction

Stopping power (SP), the inelastic mean free path (IMFP), the continuous slowing down approximation-range (CSDA-range) (R) and the energy straggling parameter are important for application such as radiation biology, electron beam lithography, and chemical analyses of surface regions of a solid and in calculation of radiation dose in radiotherapy. The principal characteristic of ionizing radiation is that it has sufficient energy to break any chemical bond and to cause ionization in all materials. Whenever the energy of a particle exceeds the ionization potential of a molecule, a collision with the molecule might lead to ionization. The knowledge of the mean free path and CSDA-range of electrons is important, especially at low energies; in line with this, number of authors has made associated studies of biological compounds[1-5].

For electrons of low energies, the inelastic interaction characteristics, the stopping power, the mean free path and the CSDA-range cannot be obtained directly from experiments or from Bethe's SP theory, the latter giving accurate SPs at energies larger than 10 keV. At lower energies, the theory is, in general, invalid. For low-energy electrons, a method has been used to estimate the mentioned characteristics, based on the use of the complex dielectric function $\varepsilon(\theta, \omega)$, $\partial\theta$ and $\partial\omega$ being the momentum and energy transfer, respectively. As mentioned by Akkerman and Akkerman[3] restrictions in these theories prevent their use for a wide range of non-organic and organic materials[3]. To calculate the mean free path and the CSDA-range, another method is to make use of the inelastic differential cross section (IDCS) suggested by[6] with the generalized oscillator strength (GOS). For this, the GOS has to be calculated from matrix elements that involve numerical integration of atomic wave functions. This calculation is too complicated.

During the last few years, a number of optical data models have been proposed to compute the inelastic scattering of electrons, avoiding the calculation of the GOS from matrix elements. In recent years, have calculated the IMFP and the CSDA-range in DNA (thymine–adenine or cytosine–guanine) for low and intermediate energy ranges. These calculations were also studied for liquid water, guanine and organic molecules in the energy range 20 eV–10 keV[1,5].

In this paper, we propose a method to obtain the CSDA ranges for electrons at intermediate energy (700–50000 keV) in terms of second order polynomial fitfing. Results obtained by this procedure are compared with the available data, above 700 keV, derived from the Born–Bethe approximation.

Previous Empirical Relations for CSDA Ranges

The exact knowledge of range of electrons and positrons in several media is of practical interest for many applications in nuclear physics, radiation protection and semiconductor detector fabrication. The main effects produced by the passage of electrons through matter are: i. Non radiative collision process and ii. Radiative collision process.

Therefore the total energy loss during the passage of electron will be the sum of these two losses. In determining CSDA ranges fluctuations in energy losses are neglected and electrons are assumed to loss energy continuously along their track with a mean energy loss per unit path length given by the stopping power. Nelms[7] has calculated CSDA ranges using collisions

loss expressions. Using collision loss expressions the following equation was solved numerically by Simpson's 1/3rd rule.

$$R_{csda} = \int_0^E \left[\left| -\left(\frac{1}{\gamma}\right)\frac{dE}{dx} \right|^{\pm} \right]^{-1} dE \qquad (1)$$

Rohrlich et al[8] have tabulated CSDA ranges of electrons and positrons for several media at different energies. Tung et al[9] calculated electron ranges using electron gas model. Berger and Seltzer[10] published extensive tables containing CSDA ranges from 10 KeV to1000MeV. Gupta et al[11] also presented an empirical formula for CSDA range but it is not applicable in low energy region. According to him an empirical equation has been derived for the csda ranges of monoenergetic electrons in the energy region 0.2-10 MeV by using the empirical relation for total stopping power. The corresponding equation for csda ranges is

$$R(T_O) = \frac{mc^2}{sz + 1.3230}\left[\frac{\gamma^{az+b-1}}{az + b - 1} + \frac{1}{\gamma}\right]_{1.1957}^{\gamma} \qquad (2)$$

Proposed relation for CSDA ranges

In general the second order polynomial fitting is a simple method for searching out any empirical relation. However, the ration for continuous slowing down approximation ranges should be simple enough to get easily evaluation. One can infer from equations (1 and 2) that the CSDA ranges of electrons as well as that of positrons depend not only upon the incident kinetic energy of these particles, but also on the nature of the material through which they traverse. Tan et al[12] have proposed a simple empirical relation for CSDA ranges for electrons with energies between 25 to 200 keV by the following relation,

$$R^{-}_{csda} = 190 \times 10^{-6}\left(\frac{A}{Z}\right)^{2.5} E^{1.6} \quad g/cm^2 \qquad (3)$$

Where A, Z and E are atomic weight, atomic number and energy respectively. This relation is valid for atomic numbers 30 to 92 with error comprising 2 to 10 %. The drawback of the relation is that it is valid for very small energy range and does not give any information for lower atomic number. We have plotted graphs between available CSDA ranges values vs $\left(\frac{A}{Z}\right)E^{0.25}$ and data are fitting with second order polynomial equation. Which are presented in following figures 1 to 6. Using this idea we have been able to find analytically convenient and simple empirical relation for CSDA ranges of electrons and positrons in intermediate energy regions 700 to 50000 keV by the following relation,

$$R^{\pm} = KX^2 + LX + M \qquad (4)$$

Where = K, L and M are constants. The value of 'X = $(A/Z)E^{0.25}$, depends on atomic weight (A), atomic number (Z) and energy (E). In equation (4) superscript (+) and (-) stands for positron and electron respectively. The values of constants are presented in table 1 (for electrons) and 2 (for positrons).

Comparison between proposed and reported values

Tan[12] relation has been verified by proposed relation (4). This relation has been used to calculate CSDA ranges of electrons and positrons in different elements for various energies in their prescribed energy regions[10]. The calculated values for electrons thus obtained were compared with the standard values due to Berger and Seltzer[10]. In order to compare evaluated values of CSDA ranges of positrons, following method has been adopted. The evaluated values of CSDA ranges have been presented in the tables 3 and 4. This relation is valid for lower atomic numbers. We note that the values of CSDA ranges evaluated by proposed relation are in close agreement with the reported data as compared to the values reported by previous researchers so far.

Conclusion

From the above results obtained using the proposed empirical relation (4), it is quite obvious that the CSDA ranges of materials can be expressed in terms of energy and atomic number of the material. We come to the conclusion that energy of the material is key parameter for the calculation of CSDA ranges. It is also noteworthy that proposed empirical relation is simpler, widely applicable and values obtained are in better agreement with the experimental and theoretical data as compared to the empirical relations proposed by previous researchers[11,12].

Acknowledgements

One of the authors (Dr. A. S. Verma, PH/08/0049) is thankful to the University Grant Commission New Delhi, India for supporting this research under the scheme of U.G.C. Dr. D.S. Kothari Post Doctoral Fellowship.

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Table-1
Values of constants for electrons

Materials	K	L	M	Regression coefficients
C	6.92876 ±0.37645	-1.24036 ±0.04492	0.05889 ±0.00116	0.99964
Al	4.3131 ±0.13056	-0.84438 ±0.01503	0.04449 ±3.74316E-4	0.99995
Cu	0.79213 ±0.34872	-0.34752 ±0.03802	0.02729 ±8.96947E-4	0.99957

Table-2
Values of constants for positrons

Materials	K	L	M	Regression coefficients
C	6.94808 ±0.33542	-1.25451 ±0.04003	0.06002 ±0.00103	0.99973
Al	4.27644 ±0.13134	-0.84809 ±0.1512	0.04512 ±3.76549E-4	0.99995
Cu	0.59092 ±0.38837	-0.33413 ±0.04234	0.02762 ±9.98923E-4	0.9995

Table-3
Values of CSDA ranges for electrons of Carbon, Aluminium and Copper

E keV	C This work	C [10]	Al this work	Al [10]	Cu this work	Cu [10]
700	0.401	0.316	0.369	0.354	0.342	0.409
800	0.398	0.376	0.413	0.42	0.449	0.484
900	0.409	0.437	0.464	0.487	0.552	0.56
1000	0.429	0.498	0.519	0.554	0.654	0.637
1250	0.508	0.653	0.668	0.723	0.897	0.828
1500	0.616	0.81	0.829	0.891	1.128	1.017
2000	0.878	1.121	1.164	1.223	1.560	1.389
5000	2.737	2.925	3.128	3.092	3.654	3.408
10000	5.698	5.657	5.953	5.859	6.281	6.183
15000	8.353	8.202	8.391	8.328	8.413	8.472
20000	10.775	10.59	10.576	10.56	10.268	10.43
25000	13.020	12.94	12.579	12.6	11.935	12.13
30000	15.126	14.98	14.444	14.5	13.466	13.65
35000	17.117	17.02	16.197	16.26	14.891	15.01
40000	19.012	19.12	17.859	17.89	16.230	16.24
45000	20.826	20.83	19.443	19.44	17.498	17.38
50000	22.569	22.8	20.961	20.88	18.705	18.42

Table-4
Values of CSDA ranges for positrons of Carbon, Aluminium and Copper

E keV	C this work	C [10]	Al this work	Al [10]	Cu this work	Cu [10]
700	0.394	0.315	0.365	0.355	0.33	0.411
800	0.395	0.376	0.413	0.422	0.45	0.488
900	0.409	0.438	0.466	0.49	0.56	0.567
1000	0.432	0.5	0.524	0.559	0.67	0.646
1250	0.519	0.661	0.682	0.732	0.93	0.843
1500	0.635	0.821	0.850	0.905	1.17	1.04
2000	0.910	1.141	1.197	1.247	1.63	1.427
5000	2.838	2.993	3.218	3.171	3.81	3.553
10000	5.887	5.839	6.111	6.016	6.53	6.427
15000	8.613	8.471	8.601	8.544	8.73	8.803
20000	11.098	10.94	10.831	10.83	10.64	10.82
25000	13.400	13.26	12.875	12.92	12.35	12.58
30000	15.557	15.47	14.776	14.84	13.93	14.13
35000	17.596	17.57	16.563	16.63	15.39	15.52
40000	19.537	19.57	18.256	18.3	16.76	16.78
45000	21.393	21.48	19.870	19.86	18.06	17.93
50000	23.177	23.32	21.416	21.33	19.30	18.99

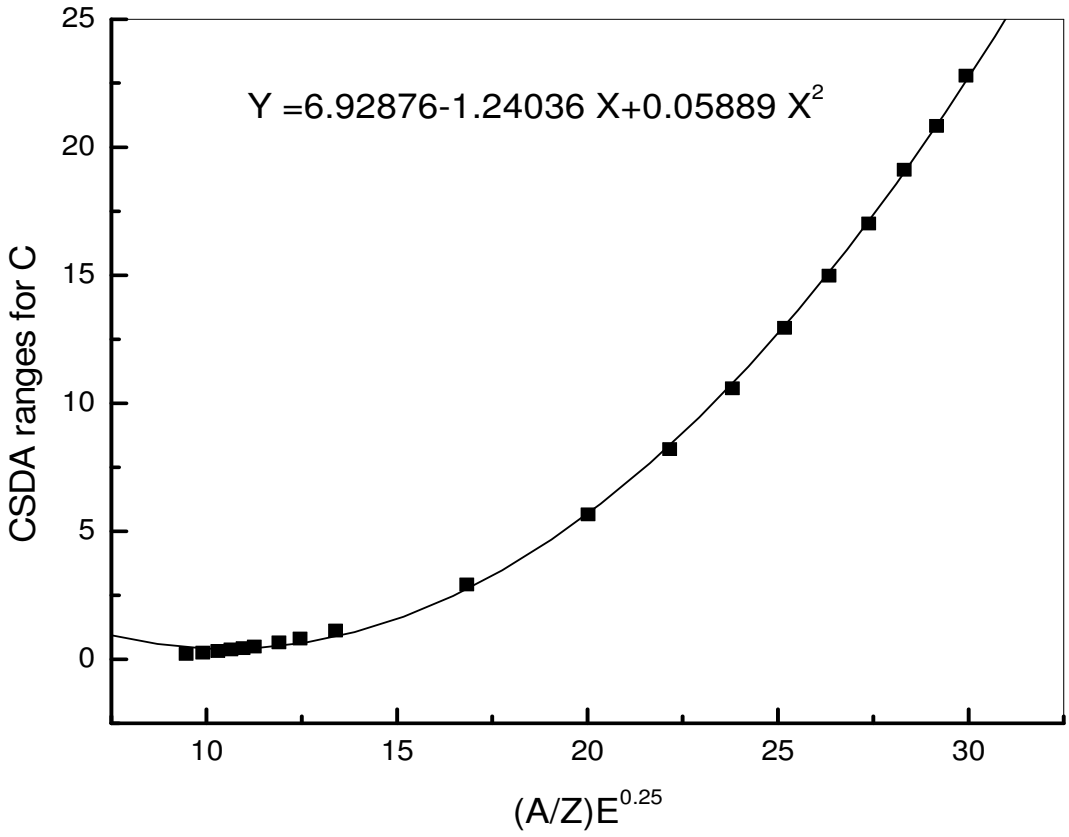

Figure-1
In the plot of CSDA ranges (for electrons) and $(A/Z)E^{0.25}$ of Carbon lie on a polynomial line[10]

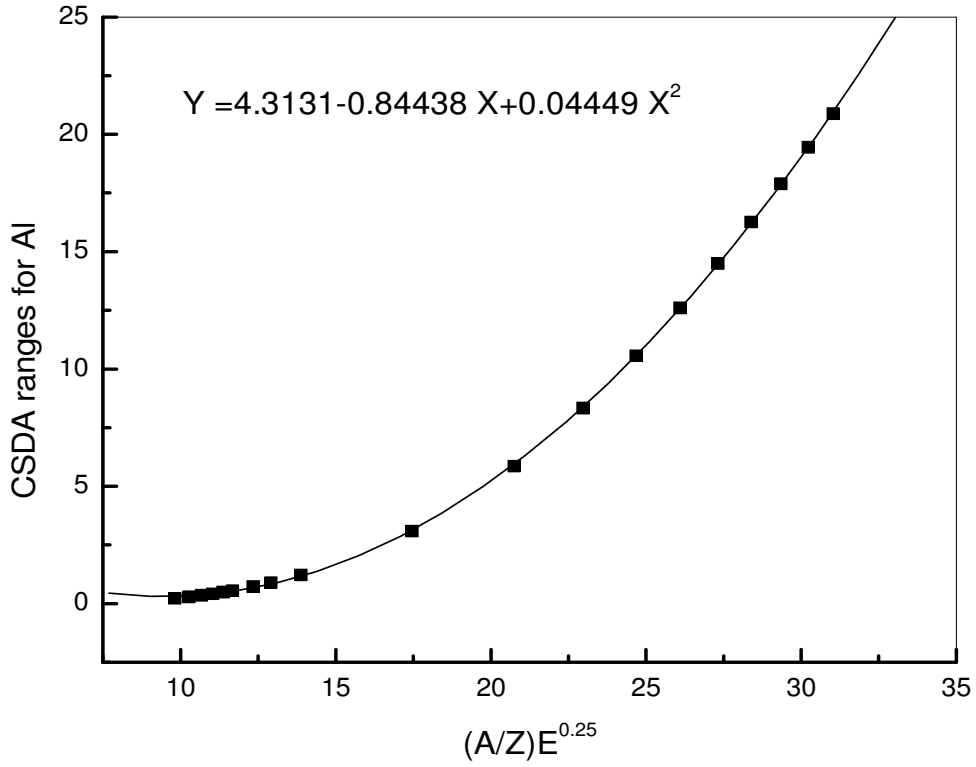

Figure-2
In the plot of CSDA ranges (for electrons) and $(A/Z)E^{0.25}$ of Aluminium lie on a polynomial line[10]

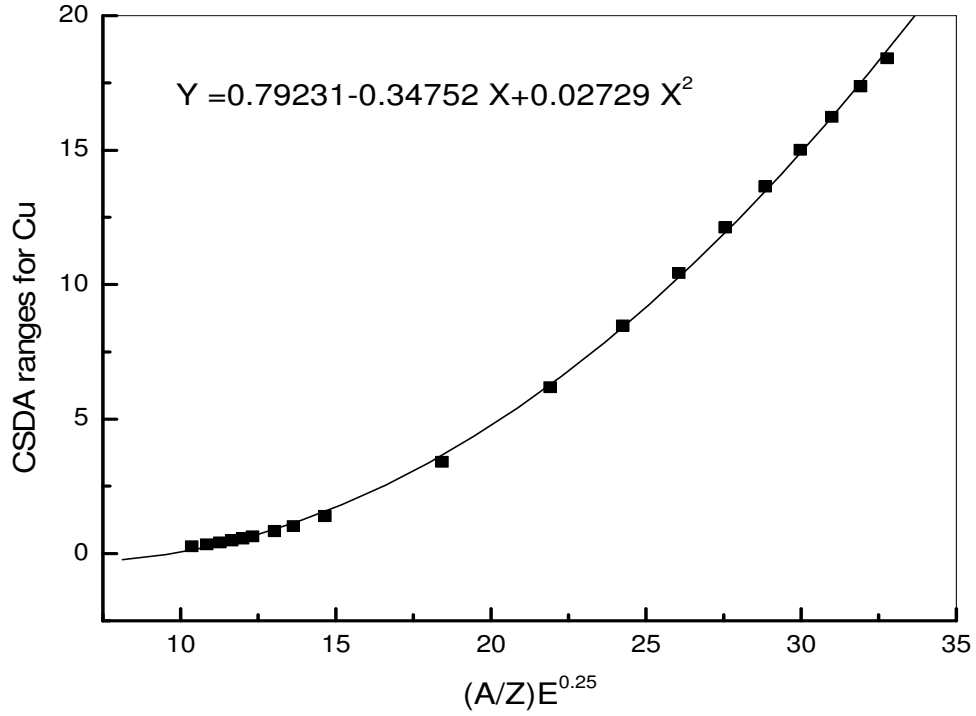

Figure-3
In the plot of CSDA ranges (for electrons) and $(A/Z)E^{0.25}$ of Copper lie on a polynomial line[10]

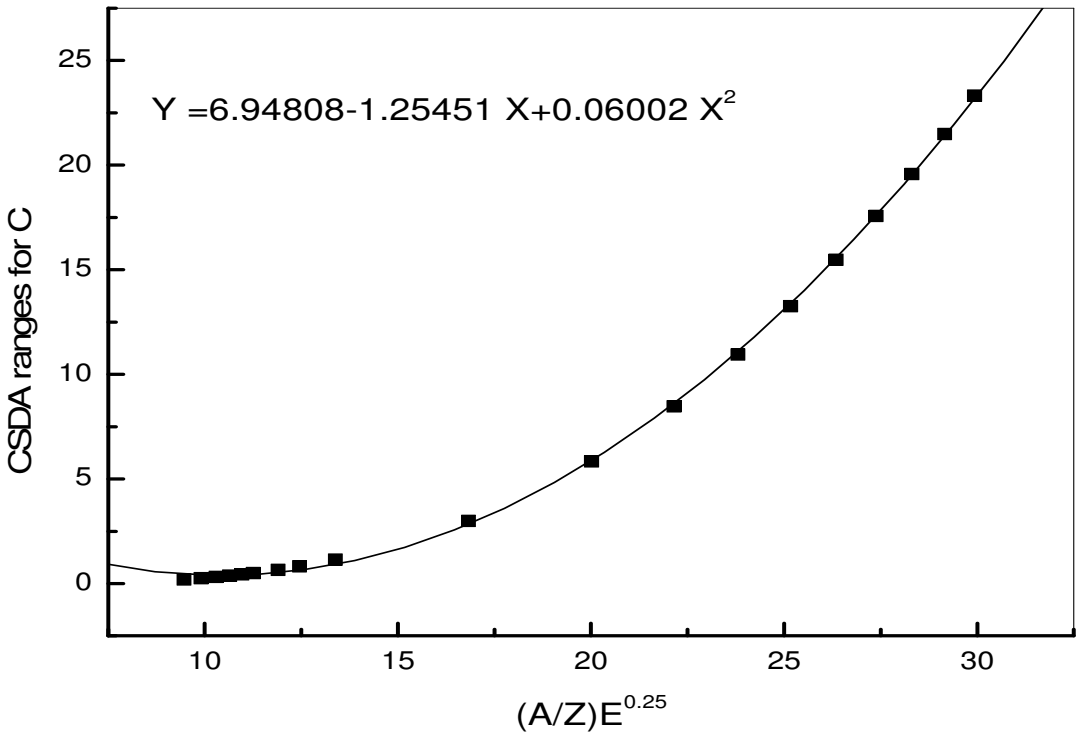

Figure-4
In the plot of CSDA ranges (for positrons) and $(A/Z)E^{0.25}$ of Carbon lie on a polynomial line[10]

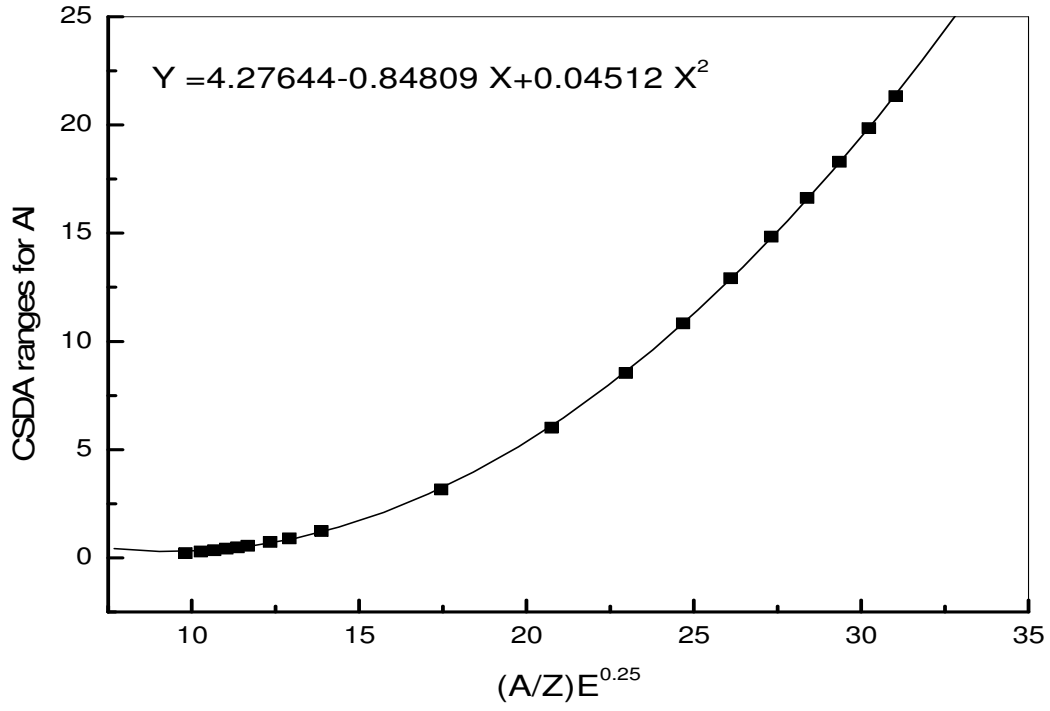

Figure-5
In the plot of CSDA ranges (for positrons) and $(A/Z)E^{0.25}$ of Aluminium lie on a polynomial line[10]

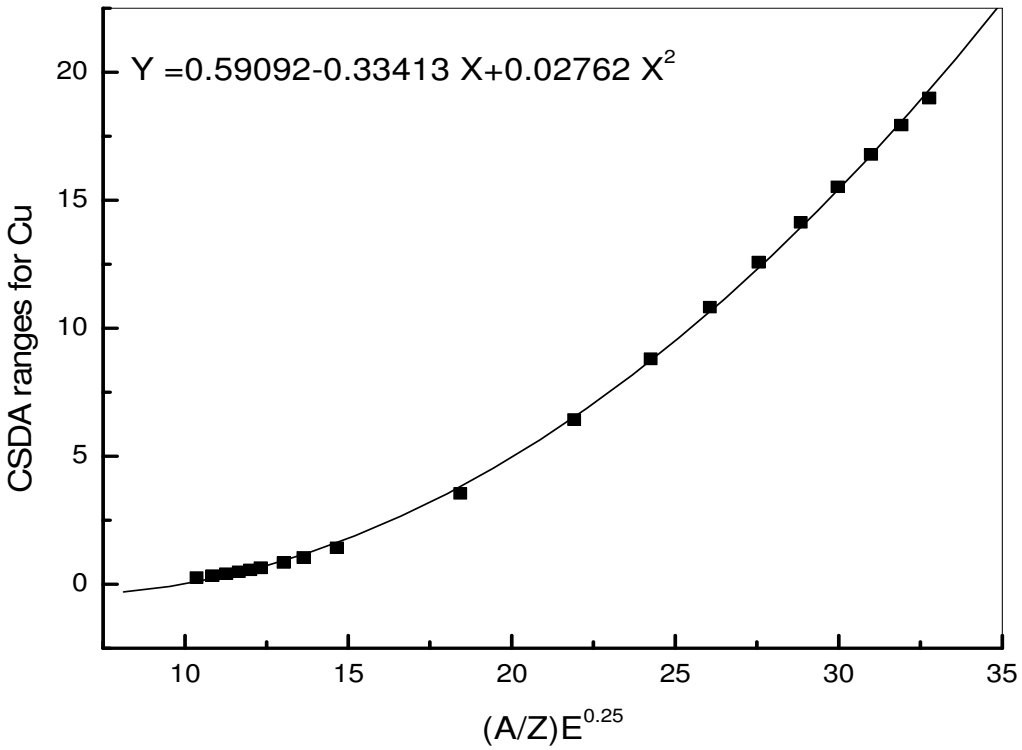

Figure-6
In the plot of CSDA ranges (for positrons) and $(A/Z)E^{0.25}$ of Copper lie on a polynomial line[10]