Stopping Power of Electrons and Positrons for C, Al, Cu, Ag, Au, Pb, Fe, U, Ge, Si and Mo

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Abstract

In this paper we present an empirical relation for total stopping power keV in terms of total energy (kinetic energy + rest mass energy) for electrons and positrons from 20 keV to 50000 and have been fitted by a two parameter approximation. These parameters depend upon the atomic number (Z) of the absorber and are applicable in absorbers of atomic number from Z=1 to 92. A fairly good agreement has been found between our simplified values for total stopping power of electrons and positrons for Carbon, Aluminum, Copper, Silver, Gold, Lead, Iron, Uranium, Germanium, Silicon and Molybdenum and that of Berger and Seltzer calculated values.

Keywords: Stopping power, Intermediate energy range, Atomic number

1. Introduction

The total stopping power for electron and positron in matters is an effective tool for understanding their interaction mechanism with matter. A survey reveals that analytical expression for the total stopping power is complicated in nature. Estimation of the stopping power for electrons and positrons in matter from these analytical expressions is tedious and involves use of mean excitation and ionization energies. A considerable amount of empirical work has been done during the last few years [Batra, 1973; Batra, 1970; Gupta, 1982; Unak, 1995], on total stopping power of materials. Nuclear physics theorists can predict total stopping power, csda ranges and related properties very accurately. The simple formula for the stopping power of electrons and positrons in different absorbers are commonly needed for many applications in nuclear spectroscopy, radiation dosimetery, surface layer analysis, physics of organic scintillators and semiconductor detectors. The total stopping power of electrons and positrons is defined as the mean energy loss per unit path length due to the ionization and excitation losses as well as the radiation loss. The theory of collision loss of electrons and positrons has been developed by many researchers [Berger, 1983; Seltzer, 1982], for the material dependent properties and energy dependent parameters to facilitate the evaluation of collision stopping power of electron and positron and gave an approximate formula for evaluating the radiation loss of electron [Paul, 2003].

Recently [Akar, 2005; Gumus, 2005; Oller, 2006; Tanuma, 2008; Pauling, 1960; Verma, 2009; Verma, 2008], there have been some significant breakthroughs in these and related areas. These improvements depend heavily on new developments in empirical techniques, and to a greater extent on the insights gained through close collaborations between theorists and experimentalists doing research on physical properties of solids. Empirical concepts such as valence electron, ionic charge, atomic number, electro negativity and energy are then useful [Batra, 1973; Batra, 1970; Gupta, 1982; Unak, 1995; Akar, 2005; Gumus, 2005; Oller, 2006; Tanuma, 2008; Pauling, 1960; Verma, 2009; Verma, 2008]. These concepts are directly associated with the character of the chemical bond and thus provide means for explaining and classifying many basic properties of molecules and solids. In many cases empirical relations do not give highly accurate results for each specific material, but they still can be very useful. In particular, the simplicity of empirical relations allows a broader class of researchers to calculate useful properties, and often trends become more evident. In this paper, we have presented empirical relation for total stopping power of low energy electrons and positrons. In the modified proposed empirical relation only the atomic number, density and total energy of electrons and positrons are required as input parameters, thereby the computation of the stopping power becomes trivial; and the results reveals are comparable to the experimental and theoretical values. Our method turns out to be widely applicable.

2. Theoretical concepts

The stopping power has been used in Monte Carlo simulations of electron transport relevant to electron probe microanalysis [Gauvin, 2005; Ritchie, 2005; Salvat, 2005]. The Bethe stopping power equation [Bethe, 1930; 1933; 1953] has been used extensively for energies where it is expected to be valid, but there is a scarcity of data at lower energies. The classical Bethe theory on the interaction of electrons with matter has been based on the Born approximation. Stopping powers calculated from the Bethe equation are available from a NIST database for electron energies of 10 keV and above [Berger, 2005]. Several empirical relations are given in literature to simplify the expressions for stopping power. One of them is due to Sargent [Sargent, 1928]. His expression for the rate of change of velocity of low energy (<100 keV) electrons in Aluminum is

$$-d\beta/dx = 2.2/\ \beta^3 \tag{1}$$

β is the ratio of velocity of electron to velocity of light and thickness **x** is expressed in cms.

This relation is limited to low energies and valid for Aluminum only. Further it cannot differentiate between electron and positron.

Heitler [1936] established a relation for collision stopping power which is valid for somewhat higher energies also. This is given by

$$-(dE/dx)_{ion} = \xi\ \ln(\eta\ W) \tag{2}$$

W is the total energy expressed in MeV and ξ and η are the constants which differ from material to materials. Their values for Aluminum and Copper are,

Al ξ=0.22 MeV cm^2/gm η=316MeV^{-1}

Cu ξ=0.21 MeV cm^2/gm η=187MeV^{-1}

This expression does not take into account bremsstrahlung losses. Also it cannot differentiate between electron and positron.

According to Batra and Sehgal [Batra, 1973; 1970; 1972] the total stopping power of electron and positron may be represented by product of two functions. These functions must depend on the kinetic energy (T) of electron or positrons and the atomic number (Z) of the material. These equations take account of bremsstrahlung losses along with collision energy losses. According to them these equations were valid for energies up to 5.0 MeV for materials of atomic number up to 92.

For T≤0.5 MeV

$$(-1/\ \rho\ *\ dE/dx)_{Tot}^{\pm} = (M_1Z+C_1)\ F^{\pm}(\gamma) \tag{3}$$

$$F^{+}(\gamma) = \gamma^{2.4}/\ \gamma^{(1.9-1)}$$

$$F^{-}(\gamma) = \gamma^{2.56}/(\gamma^2-1)$$

Where ρ is the density of target material and γ is the total energy of electron or positron in electron mass unit. M_1 and C_1 are constants.

For 0.25 meV≤T≤5.0 MeV

$$(-1/\ \rho * dE/dx)^{\pm} = (M_2Z+C_2)[\ \gamma^2/\ \gamma^{a\pm z+b\pm}-1] \tag{4}$$

Superscripts ± represents for positron and electron respectively. M_2, C_2, $a^{\pm}$ and $b^{\pm}$ are constants.

Pal et al [1986] developed a similar formula on the lines of Batra and Sehgal [Batra, 1973; 1970; 1972] but with different set of constants,

$$-1/\ \rho\ (d\ \gamma\ /dx)^{\pm} = (MZ+N)\ (P_0^{\pm} + P_1^{\pm}\ \gamma) \tag{5}$$

$P_n^{\pm} = A_n^{\pm} + B_n^{\pm}Z + C_n^{\pm}Z^2$, where A, B and C are constants and n = 0 & 1. This relation holds well from 5 to 1000meV.

Recently, Tanuma et al [2008] has calculated electron stopping power for 31 elemental solids. These stopping powers are determined with an algorithm previously used for the calculation of electron inelastic mean free paths and from energy loss functions derived from experimental optical data. The stopping power calculations are valid for electron energies between 100 eV and 30keV. Through polynomial fitting, we have able to find out a single empirical relation for total stopping power from 20 keV to 50000 keV. It is inferred that the total stopping power of electrons as well as positrons depends not only upon the incident kinetic energies of these particles, but also on the nature of the material through which they traverse. It was noticed that the dependence of total stopping power on incident kinetic energy could only be met through the use of some suitable power function. The new stopping power relation for electrons and positrons of energies 20keV to 50000 keV is

$$-1/\rho\ (dE/dS)^{\pm}_{tot} = (MZ+C)\ (\gamma^{A\pm Z+B\pm})/\gamma(K^{\pm}-1) \quad (6)$$

Where ρ denotes the density of the material, γ represents the total energy (i.e. sum of kinetic energy and electron rest mass energy) of electrons or positrons in units of electron rest mass, Z is atomic number of the material and M, C and K are constants. Superscript ± represents for positrons & electrons respectively.

3. Results and Discussion

Information on stopping power is essential in many fields involving radiation. Their accuracy may critically affect calculations, measurements and interpretation of experiments. Research concerning the stopping power has taken the position of the basic theme in the fields of ion-matter interactions for a long time. Despite the long history of stopping power research, the current knowledge, both experiment and theoretical, is far from being complete, and is often inadequate for the determination of stopping power values of a variety of materials and for a wide range of particle energies. The proposed empirical relation (6) has been used to evaluate the stopping power of positrons and electrons with incident kinetic energies from 20 keV to 50000 keV for Carbon, Aluminum, Copper, Silver, Gold, Lead, Iron, Uranium, Germanium, Silicon and Molybdenum in a very simplified manner. The values of stopping power thus obtained are presented in tables 2-6. These values have been compared with the values tabulated by Berger and Seltzer. We note that the values of stopping power evaluated by proposed relation are in close agreement with the experimental data as compared to the values reported by previous researchers so far.

4. Summary and Conclusions

From the above results obtained using the proposed empirical relation (6), it is quite obvious that the stopping power 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 stopping power. 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 so far.

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References

Akar, A. and Gumus, H. (2005). Electron stopping power in biological compounds for low and intermediate energies with the generalized oscillator strength (GOS) model. *Raditation Phys. Chem.*, 73, 196.

Batra, R. K., Sehgal, M. L. (1970). Empirical relation for total stopping power of positrons and electrons. *Nuclear Physics A.*, 156, 314.

Batra, R. K., Sehgal, M. L. (1973). Approximate stopping power law of electrons and Positrons. *Nucl. Inst Methods.*, 109, 565.

Batra R. K. and Sehgal,M. L. (1972). Empirical relation for total stopping power of positons and electrons. *Nuclear Physics A*., 196, 638.

Berger, M. J., Coursey, J. S., Zucker, M. A. and Chang, J. (2005). Stopping Power and Range Tables for Electrons, Positrons, and Helium Ions (http://physics.nist.gov/PhysRefData/Star/Text/contents.html).

Berger, M.J. and Seltzer, S.M. (1983). Nat. Bur. Stand. Report No. *NBSIR,* 82-2550-A.

Bethe, H. (1930). *Ann. Phys.*, 5, 325.

Bethe, H. A. and Ashkin, J. (1953). *In Experimental Nuclear Physics*, edited by E.Segre (Wiley, New York, 1953),166.

Bethe, H. (1993). In Handbuch der Physik, edited by H. Geiger and K. Scheel (Springer, Berlin, 1933), Vol. 24/1, 273.

Gauvin, R. (2005). X -ray microanalysis of real materials using Monte Carlo simulations. *Surf. Interface Anal.*, 37,875.

Gumus, H. (2005). Simple stopping power formula for low and intermediate energy electrons. *Raditation Phys. Chem.*, 72, 7.

Gupta, S. K., Govil, J. C., Gupta,K. K., Tyagi,R. K. and Verma,O. P. (1982). Empirical equations for the stopping power and c.s.d.a. range difference of 0.2 to 10 MeV positrons. *Int. J. Appl. Radiat. Isot*., 33, 773.

Heitler, W. (1936). The Quantum Theory of Radiation (Oxford Univ. Press, London). 220.

Oller, J. C., Munoz, A., Percz, J. M., Blanco, F., Vieira, P. L. and Garcia, G. (2006). Inelastic scattering and stopping power of electrons in methane based tissue equivalent materials at intermediate and high energies, 10–10 000 eV., *Chem. Phys. Letts.*, 421, 439.

Pal, P.B., Varshney, V.P. and Gupta, D.K. (1986). Total Stopping Power Formulae for High Energy Electrons and Positrons. *Nucl. Instru. Meth*, B., 16, 1.

Paul, H. and Schinner, A. (2003). Atomic Data and Nucl Data Tables., 85, 377.

Pauling, L. *The Nature of the Chemical Bond*, 3rd, ed. (Cornell University Press, Ithaca, 1960).

Ritchie, N. W. M. (2005). A new Monte Carlo application for complex sample geometries.Surf. *Interface Anal.*, 37, 1006.

Salvat, F., Llovet, X.,Fernandez-Varea, J. M. and Sempau, J. (2005). Monte Carlo simulation of X-ray emission using the general-purpose code PENELOPE. *Surf. Interface Anal*., 37, 1054.

Sargent, B.W. (1928). *Trans. Roy. Soc*. Canada., 22/3, 179.

Seltzer, S.M. and Berger, M.J. (1982). Procedure for calculating the radiation stopping power for electrons. *Int.J.Appl.Radiat. Isot*., 33, 1219.

Tanuma, S., Powell, C. J. and Penn, D. R. (2008). Calculations of stopping powers of 100 eV-30 keV electrons in 31 elemental solids. *J. Appl. Phys.*, 063707,103.

Unak, T. Ongun, B., Unak, P., and Kumru, M. N. (1995). Comparison of the calculated and measured stopping powers of low-energy electrons in different metals. *Appl Radiat. Isot.*, 46, 561.

Verma, A. S. (2008). Bond-stretching and bond-bending force constant of binary tetrahedral ($A^{III}B^{V}$ and $A^{II}B^{VI}$) semiconductors. *Phys. Letts. A*., 372, 7196.

Verma, A. S. (2009). Thermal properties of chalcopyrite semiconductors. *Phil. Mag.*, 89, 183.

Table 1a. Values of constants

Range (Atomic Number)	M	C
$1 \le Z \le 10$	-0.3215	3.675
$10 \le Z \le 36$	-0.0132	1.677
$Z > 36$	-0.00655	1.4177

Table 1b. Values of constants

Energy	K^-	K^+
20keV<E≤10000keV	3.95	3.75
15000keV<E≤50000keV	3.86	3.62

Table 2. Values of stopping power for electrons

E(KeV)	CARBON			ALUMINIUM			COPPER			SILVER		
	This work	[5]	%error	This work	[5]	%error	This work	[5]	%error	This work	[5]	%error
20	12.42	11.77	5.5	10.71	9.85	8.8	9.24	8.08	14.3	7.94	7.04	12.9
30	8.66	8.63	0.4	7.48	7.29	2.5	6.45	6.06	6.6	5.56	5.32	4.5
40	6.79	6.95	2.4	5.86	5.92	0.9	5.07	4.95	2.5	4.37	4.37	0.1
50	5.67	5.9	4	4.9	5.05	2.9	4.24	4.24	0.0	3.66	3.76	2.6
60	4.92	5.18	5	4.26	4.45	4.2	3.69	3.75	1.7	3.19	3.34	4.4
70	4.39	4.65	5.6	3.8	4.01	5.0	3.30	3.39	2.7	2.86	3.02	5.5
80	4	4.25	5.9	3.46	3.67	5.5	3.01	3.11	3.4	2.61	2.78	6.2
90	3.7	3.93	6	3.2	3.4	5.8	2.78	2.89	3.8	2.42	2.59	6.6
100	3.45	3.68	6	2.99	3.19	6.0	2.61	2.72	4.0	2.27	2.43	6.9
150	2.74	2.89	5	2.38	2.52	5.5	2.09	2.16	3.6	1.83	1.95	6.4
200	2.4	2.49	3.3	2.09	2.18	4.1	1.84	1.88	2.1	1.62	1.70	4.8
250	2.21	2.25	1.5	1.93	1.98	2.6	1.71	1.71	0.3	1.51	1.56	3.0
300	2.09	2.09	0.15	1.83	1.85	1.1	1.62	1.60	1.4	1.44	1.46	1.1
350	2.01	1.98	1.7	1.76	1.76	0.2	1.57	1.52	3.1	1.40	1.40	0.6
400	1.95	1.9	3.1	1.72	1.69	1.4	1.54	1.47	4.5	1.38	1.35	2.3
450	1.91	1.84	4.3	1.68	1.64	2.5	1.51	1.43	5.9	1.36	1.32	3.7
500	1.89	1.79	5.4	1.66	1.6	3.4	1.50	1.40	7.0	1.35	1.29	5.0
600	1.84	1.72	7.1	1.63	1.55	4.8	1.48	1.36	8.9	1.35	1.26	7.2
700	1.82	1.68	8.3	1.61	1.52	5.9	1.47	1.33	10.4	1.35	1.24	8.9
900	1.79	1.63	9.9	1.6	1.49	7.0	1.47	1.31	12.3	1.37	1.23	11.4
1000	1.79	1.62	10.4	1.59	1.49	7.2	1.48	1.31	13.0	1.38	1.23	12.1
1500	1.78	1.6	10.9	1.6	1.49	7.0	1.51	1.33	13.9	1.44	1.27	13.9
2000	1.77	1.61	10.3	1.61	1.52	5.8	1.54	1.36	13.3	1.50	1.32	13.8
2500	1.78	1.63	9.1	1.62	1.55	4.4	1.57	1.41	12.1	1.55	1.38	12.8
3000	1.78	1.65	7.9	1.63	1.58	3.0	1.60	1.45	10.5	1.60	1.43	11.5
3500	1.78	1.67	6.8	1.63	1.61	1.6	1.62	1.49	9.0	1.64	1.49	10.0
4000	1.78	1.69	5.6	1.64	1.64	0.3	1.64	1.53	7.4	1.68	1.55	8.3
4500	1.78	1.71	4.5	1.65	1.66	0.9	1.66	1.57	5.8	1.71	1.60	6.7
5000	1.78	1.72	3.5	1.65	1.69	2.1	1.68	1.61	4.2	1.74	1.66	5.0
10000	1.79	1.88	4.7	1.7	1.92	11.8	1.80	2.00	9.8	1.97	2.19	10.1
15000	2.45	2.02	21.4	2.34	2.14	9.7	2.56	2.38	7.7	2.88	2.71	6.3
20000	2.51	2.14	17.6	2.43	2.34	3.7	2.71	2.75	1.5	3.11	3.27	4.7
25000	2.57	2.26	13.8	2.5	2.55	1.8	2.83	3.12	9.3	3.31	3.75	11.8
30000	2.61	2.38	10.1	2.56	2.75	6.9	2.93	3.49	16.0	3.48	4.27	18.6
35000	2.65	2.49	6.6	2.61	2.95	11.5	3.02	3.86	21.7	3.63	4.80	24.4
40000	2.69	2.61	3.2	2.65	3.15	15.7	3.10	4.23	26.7	3.76	5.33	29.4
45000	2.72	2.72	0.01	2.69	3.35	19.6	3.18	2.72	16.7	3.89	5.86	33.7
50000	2.75	2.84	3	2.73	3.55	23.1	3.24	4.98	34.8	4.00	6.40	37.4

Table 3. Values of stopping power for electrons

E(KeV)	***GOLD***			***LEAD***			***URANIUM***			***IRON***		
	This work	[5]	%error	This work	[5]	%error	This work	[5]	%error	This work.	[5]	%error
20	6.48	5.62	15.3	6.34	5.48	15.7	5.88	5.23	12.5	9.51	8.47	12.3
30	4.55	4.32	5.4	4.45	4.21	5.6	4.13	4.03	2.5	6.65	6.33	5.0
40	3.58	3.58	0.2	3.51	3.50	0.4	3.26	3.35	2.7	5.22	5.16	1.1
50	3.01	3.10	3.0	2.95	3.03	2.8	2.74	2.91	5.8	4.36	4.42	1.3
60	2.63	2.77	5.0	2.58	2.71	4.8	2.40	2.60	7.7	3.80	3.91	2.8
70	2.36	2.52	6.3	2.31	2.47	6.2	2.15	2.37	9.1	3.40	3.59	5.5
80	2.16	2.33	7.1	2.12	2.28	7.1	1.97	2.19	9.9	3.10	3.24	4.4
90	2.01	2.17	7.7	1.97	2.13	7.6	1.83	2.05	10.4	2.86	3.01	4.8
100	1.89	2.05	8.0	1.85	2.01	7.9	1.73	1.93	10.7	2.68	2.82	5.0
150	1.54	1.66	7.7	1.51	1.63	7.7	1.41	1.57	10.4	2.14	2.24	4.4
200	1.38	1.47	6.0	1.35	1.44	6.1	1.27	1.39	8.7	1.89	1.95	2.9
250	1.30	1.35	4.0	1.27	1.33	4.2	1.20	1.29	6.6	1.75	1.77	1.2
300	1.25	1.27	1.9	1.23	1.26	2.1	1.16	1.22	4.5	1.66	1.66	0.4
350	1.23	1.22	0.1	1.21	1.21	0.2	1.14	1.17	2.4	1.61	1.58	2.0
400	1.21	1.19	2.0	1.20	1.18	1.8	1.14	1.14	0.4	1.57	1.52	3.4
450	1.21	1.16	3.8	1.19	1.15	3.5	1.13	1.12	1.4	1.55	1.48	4.6
500	1.21	1.15	5.4	1.19	1.14	5.2	1.14	1.10	3.1	1.53	1.45	5.7
600	1.22	1.13	8.3	1.21	1.12	7.9	1.15	1.09	6.1	1.51	1.40	7.6
700	1.24	1.12	10.6	1.22	1.11	10.3	1.18	1.08	8.7	1.50	1.38	9.0
900	1.28	1.12	14.3	1.27	1.12	14.0	1.23	1.09	12.7	1.50	1.35	10.7
1000	1.31	1.13	15.6	1.30	1.12	15.4	1.26	1.10	14.3	1.50	1.35	11.3
1500	1.42	1.19	19.8	1.42	1.18	19.7	1.39	1.16	19.6	1.53	1.37	12.1
2000	1.53	1.26	21.5	1.52	1.26	21.3	1.51	1.24	22.0	1.56	1.40	11.4
2500	1.62	1.33	21.9	1.62	1.33	21.7	1.62	1.32	23.0	1.59	1.44	10.1
3000	1.70	1.40	21.5	1.71	1.41	21.4	1.72	1.40	23.2	1.61	1.48	8.7
3500	1.78	1.47	20.7	1.79	1.48	20.7	1.81	1.47	22.9	1.63	1.52	7.2
4000	1.85	1.54	19.7	1.86	1.55	19.8	1.89	1.55	22.3	1.65	1.56	5.6
4500	1.91	1.62	18.4	1.93	1.63	18.6	1.97	1.63	21.4	1.66	1.60	4.1
5000	1.97	1.69	17.0	1.99	1.70	17.3	2.05	1.70	20.4	1.68	1.64	2.5
10000	2.44	2.39	2.4	2.49	2.41	3.3	2.63	2.44	7.5	1.79	2.01	10.9
15000	3.77	3.08	22.4	3.86	3.12	24.0	4.15	3.19	30.2	2.52	2.36	7.1
20000	4.24	3.79	12.1	4.36	3.83	13.8	4.75	3.95	20.3	2.66	2.70	1.7
25000	4.65	4.50	3.4	4.79	4.55	5.3	5.27	4.71	11.9	2.77	3.05	9.2
30000	5.02	5.22	3.9	5.18	5.28	1.9	5.74	5.47	4.8	2.86	3.40	15.7
35000	5.35	5.94	10.0	5.53	6.01	8.0	6.17	6.25	1.3	2.95	3.74	21.3
40000	5.65	6.67	15.2	5.85	6.75	13.2	6.57	7.03	6.5	3.02	4.09	26.1
45000	5.93	7.40	19.8	6.16	7.49	17.8	6.94	7.81	11.1	3.09	4.43	30.4
50000	6.20	8.13	23.8	6.44	8.23	21.7	7.30	8.59	15.1	3.15	4.78	34.2

Table 4. Values of stopping power for electrons

E(KeV)	GERMANIUM			MOLYBEDNUM			SILICON		
	This work	[5]	%error	This work	[5]	%error	This work	[5]	%error
20	8.96	7.66	17.0	8.17	7.26	12.6	10.62	10.11	5.1
30	6.26	5.75	9.0	5.72	5.47	4.5	7.41	7.49	1.0
40	4.92	4.70	4.6	4.49	4.49	0.1	5.81	6.08	4.3
50	4.12	4.04	2.0	3.76	3.86	2.5	4.86	5.18	6.3
60	3.58	3.57	0.3	3.28	3.42	4.2	4.22	4.57	7.5
70	3.20	3.23	0.8	2.93	3.10	5.3	3.77	4.12	8.3
80	2.92	2.97	1.5	2.68	2.85	6.0	3.44	3.77	8.8
90	2.71	2.76	2.0	2.48	2.65	6.4	3.18	3.50	9.1
100	2.53	2.59	2.2	2.32	2.49	6.7	2.97	3.27	9.3
150	2.03	2.07	2.0	1.87	2.00	6.4	2.36	2.59	8.8
200	1.79	1.80	0.6	1.66	1.74	4.9	2.08	2.25	7.5
250	1.66	1.65	1.0	1.54	1.59	3.3	1.92	2.04	6.0
300	1.58	1.54	2.6	1.47	1.50	1.6	1.82	1.90	4.6
350	1.53	1.47	4.2	1.43	1.43	0.1	1.75	1.81	3.3
400	1.50	1.42	5.5	1.40	1.38	1.5	1.70	1.74	2.1
450	1.48	1.39	6.7	1.38	1.35	2.9	1.67	1.69	1.1
500	1.46	1.36	7.8	1.37	1.32	4.1	1.65	1.65	0.2
600	1.45	1.32	9.6	1.36	1.29	6.2	1.62	1.60	1.2
700	1.44	1.30	11.0	1.37	1.27	7.7	1.60	1.57	2.2
900	1.45	1.28	12.8	1.38	1.26	9.9	1.59	1.54	3.4
1000	1.45	1.28	13.3	1.39	1.26	10.7	1.59	1.53	3.7
1500	1.49	1.31	14.1	1.44	1.29	12.0	1.59	1.54	3.5
2000	1.53	1.35	13.5	1.49	1.34	11.7	1.60	1.57	2.3
2500	1.56	1.39	12.3	1.54	1.39	10.8	1.61	1.60	0.9
3000	1.59	1.44	10.8	1.58	1.44	9.4	1.63	1.63	0.5
3500	1.62	1.48	9.3	1.61	1.50	7.9	1.63	1.67	2.0
4000	1.64	1.52	7.7	1.64	1.55	6.3	1.64	1.70	3.3
4500	1.66	1.57	6.1	1.67	1.60	4.7	1.65	1.73	4.6
5000	1.68	1.61	4.6	1.70	1.65	3.2	1.66	1.76	5.7
10000	1.82	2.01	9.4	1.89	2.13	11.2	1.70	2.01	15.3
15000	2.60	2.40	8.3	2.75	2.61	5.4	2.36	2.25	5.0
20000	2.76	2.79	1.1	2.95	3.08	4.2	2.45	2.47	1.0
25000	2.89	3.17	9.0	3.12	3.56	12.3	2.52	2.70	6.5
30000	3.00	3.56	15.8	3.27	4.04	19.1	2.58	2.92	11.5
35000	3.10	3.95	21.6	3.40	4.53	24.9	2.63	3.14	16.1
40000	3.19	4.34	26.6	3.52	5.01	29.8	2.68	3.36	20.2
45000	3.27	4.73	31.0	3.63	5.50	34.1	2.72	3.58	24.0
50000	3.34	5.13	34.8	3.72	5.99	37.8	2.76	3.80	27.4

Table 5. Values of stopping power for positrons

E(KeV)	CARBON			ALUMINIUM			COPPER			SILVER		
	This work	[5]	%error	This work	[5]	%error	This work	[5]	%error	This work	[5]	%error
20	13.01	12.76	2.0	11.23	10.80	4.0	9.68	8.97	7.9	8.32	7.88	5.6
30	9.06	9.26	2.2	7.82	7.90	1.0	6.75	6.62	1.9	5.81	5.86	0.8
40	7.08	7.41	4.4	6.12	6.36	3.7	5.29	5.36	1.3	4.56	4.75	4.1
50	5.90	6.25	5.6	5.10	5.38	5.2	4.41	4.56	3.1	3.81	4.05	6.0
60	5.12	5.46	6.3	4.43	4.72	6.2	3.83	4.00	4.2	3.31	3.57	7.2
70	4.56	4.89	6.7	3.94	4.23	6.7	3.42	3.60	4.9	2.96	3.21	7.8
80	4.14	4.45	6.8	3.59	3.85	7.0	3.11	3.28	5.2	2.70	2.94	8.2
90	3.82	4.10	6.8	3.31	3.56	7.0	2.87	3.04	5.4	2.49	2.72	8.3
100	3.56	3.82	6.7	3.09	3.32	7.0	2.68	2.84	5.4	2.33	2.54	8.2
150	2.81	2.96	5.2	2.44	2.59	5.9	2.13	2.22	4.2	1.86	2.00	6.8
200	2.44	2.53	3.3	2.13	2.22	4.2	1.87	1.91	2.2	1.64	1.72	4.7
250	2.24	2.27	1.3	1.95	2.00	2.5	1.72	1.72	0.2	1.52	1.56	2.6
300	2.10	2.09	0.5	1.84	1.85	0.9	1.63	1.60	1.7	1.44	1.45	0.4
350	2.01	1.97	2.1	1.76	1.75	0.5	1.57	1.51	3.4	1.39	1.37	1.4
400	1.95	1.89	3.4	1.71	1.68	1.7	1.52	1.45	5.0	1.36	1.32	3.1
450	1.90	1.82	4.6	1.67	1.63	2.7	1.49	1.41	6.2	1.34	1.28	4.6
500	1.87	1.77	5.6	1.64	1.59	3.6	1.47	1.37	7.3	1.33	1.25	5.9
600	1.82	1.70	7.2	1.60	1.53	4.9	1.45	1.33	9.2	1.31	1.22	8.0
700	1.79	1.65	8.3	1.58	1.49	5.8	1.43	1.30	10.5	1.31	1.19	9.6
900	1.75	1.60	9.7	1.55	1.46	6.6	1.42	1.27	12.1	1.31	1.18	11.7
1000	1.74	1.58	10.0	1.55	1.45	6.7	1.42	1.27	12.5	1.32	1.17	12.3
1500	1.71	1.56	9.9	1.53	1.45	5.7	1.44	1.28	12.6	1.36	1.20	13.2
2000	1.70	1.57	8.6	1.53	1.48	3.9	1.46	1.31	11.2	1.40	1.25	12.2
2500	1.69	1.58	7.0	1.53	1.50	1.9	1.47	1.35	9.3	1.43	1.30	10.5
3000	1.69	1.60	5.4	1.53	1.53	0.0	1.49	1.39	7.3	1.46	1.35	8.7
3500	1.68	1.62	3.9	1.54	1.56	1.7	1.50	1.43	5.4	1.49	1.40	6.6
4000	1.68	1.64	2.4	1.54	1.59	3.3	1.52	1.47	3.3	1.52	1.45	4.6
4500	1.68	1.66	1.1	1.54	1.62	4.8	1.53	1.51	1.4	1.54	1.50	2.6
5000	1.67	1.68	0.2	1.54	1.64	6.2	1.54	1.55	0.5	1.56	1.55	0.6
10000	1.65	1.83	9.8	1.55	1.87	17.3	1.61	1.92	16.2	1.71	2.05	16.4
15000	2.56	1.97	30.2	2.42	2.09	16.2	2.58	2.30	12.6	2.82	2.54	10.9
20000	2.64	2.09	26.4	2.52	2.29	10.0	2.73	2.67	2.5	3.04	3.05	0.1
25000	2.71	2.21	22.5	2.60	2.50	4.1	2.86	3.04	6.0	3.23	3.56	9.2
30000	2.76	2.33	18.7	2.66	2.70	1.2	2.96	3.41	13.2	3.39	4.08	16.8
35000	2.81	2.44	15.0	2.72	2.90	6.1	3.05	3.79	19.3	3.54	4.60	23.2
40000	2.85	2.56	11.5	2.77	3.10	10.6	3.14	4.16	24.6	3.67	5.13	28.5
45000	2.89	2.67	8.1	2.82	3.30	14.7	3.21	4.34	25.9	3.78	5.66	33.1
50000	2.92	2.79	4.9	2.86	3.50	18.4	3.28	4.91	33.2	3.89	6.19	37.1

Table 6. Values of stopping power for positrons

E(KeV)	LEAD			SILICON			GERMANIUM		
	This work	[5]	%error	This work	[5]	%error	This work	[5]	%error
20	6.64	6.24	6.4	11.13	11.09	0.4	9.39	8.52	10.2
30	4.65	4.69	0.9	7.75	8.12	4.5	6.55	6.30	4.0
40	3.65	3.83	4.7	6.07	6.53	7.1	5.13	5.09	0.7
50	3.06	3.28	6.8	5.06	5.53	8.6	4.28	4.34	1.3
60	2.67	2.90	8.1	4.39	4.85	9.5	3.72	3.81	2.4
70	2.39	2.62	8.8	3.91	4.35	10.0	3.32	3.43	3.1
80	2.18	2.40	9.1	3.56	3.96	10.2	3.02	3.13	3.5
90	2.02	2.23	9.3	3.28	3.66	10.3	2.79	2.90	3.6
100	1.90	2.09	9.2	3.06	3.41	10.3	2.61	2.71	3.7
150	1.53	1.66	7.6	2.42	2.66	9.2	2.07	2.13	2.5
200	1.36	1.44	5.2	2.11	2.28	7.6	1.82	1.83	0.7
250	1.27	1.30	2.6	1.93	2.06	5.9	1.67	1.65	1.2
300	1.22	1.22	0.2	1.82	1.91	4.4	1.58	1.54	3.0
350	1.19	1.16	2.2	1.75	1.81	3.0	1.53	1.46	4.6
400	1.17	1.12	4.3	1.70	1.73	1.8	1.49	1.40	5.9
450	1.16	1.09	6.2	1.66	1.68	0.9	1.46	1.36	7.2
500	1.16	1.07	7.9	1.63	1.63	0.0	1.44	1.33	8.2
600	1.16	1.04	10.9	1.59	1.57	1.3	1.42	1.29	9.9
700	1.17	1.03	13.1	1.57	1.54	2.2	1.40	1.27	11.0
900	1.20	1.02	17.0	1.55	1.50	3.0	1.40	1.24	12.4
1000	1.21	1.03	18.3	1.54	1.49	3.1	1.40	1.24	12.8
1500	1.30	1.07	22.0	1.53	1.50	2.3	1.42	1.26	12.7
2000	1.38	1.12	23.0	1.53	1.52	0.5	1.44	1.29	11.3
2500	1.45	1.18	22.7	1.53	1.55	1.5	1.46	1.33	9.5
3000	1.51	1.24	21.9	1.53	1.59	3.4	1.48	1.37	7.5
3500	1.57	1.30	20.6	1.54	1.62	5.1	1.49	1.42	5.5
4000	1.62	1.37	18.9	1.54	1.65	6.8	1.51	1.46	3.6
4500	1.67	1.43	17.2	1.54	1.68	8.3	1.52	1.50	1.7
5000	1.72	1.49	15.3	1.54	1.71	9.7	1.53	1.54	0.2
10000	2.06	2.11	2.6	1.55	1.96	20.8	1.62	1.92	15.9
15000	3.58	2.76	29.9	2.44	2.20	11.0	2.61	2.31	12.9
20000	4.01	3.41	17.7	2.54	2.42	4.7	2.77	2.69	2.8
25000	4.39	4.08	7.5	2.62	2.65	1.1	2.90	3.08	5.9
30000	4.72	4.77	0.9	2.68	2.87	6.4	3.01	3.47	13.2
35000	5.03	5.46	7.9	2.74	3.09	11.2	3.11	3.86	19.4
40000	5.31	6.16	13.8	2.80	3.31	15.5	3.20	4.26	24.8
45000	5.57	6.87	19.0	2.84	3.53	19.5	3.28	4.65	29.4
50000	5.81	7.59	23.5	2.89	3.75	23.1	3.36	5.05	33.5