Asian Journal of Chemistry Vol. 21, No. 10 (2009), S130-134

Study of CSDA and Extrapolated Ranges of Electrons in some Selected Solvents in the Energy Range of 0.01-100 MeV

ASHOK KUMAR*, B. S. SALARIA†, SUKHPAL SINGH†, BALKRISHAN††, CHARANJEET SINGH†, and G. S. MUDAHAR†
**College of Engineering, Rampura Phul, Punjab, India.*
e-mail: ajindal99@yahoo.co.in

The continuous slowing down approximation (CSDA) ranges of electrons have been determined in some selected solvents in the energy range of 0.01-100 MeV using an analytic formulation. The results have been compared with CSDA range values obtained through ESTAR program and are found to be in close agreement. The extrapolated ranges of electrons have also been obtained for these selected solvents through calculations of multiple scattering detours.

Key Words: Solvents, CSDA range, Extrapolated range

INTRODUCTION

The knowledge of the interaction parameters of electrons in different materials is very important in the various fields such as radiotherapy, radiology, nuclear physics, health physics, basic particle physics, design of radiation dosimeters, micro dosimeters, material analysis with charged particles etc. The CSDA and extrapolated range of electrons is required to characterize a stopping media. CSDA range is a very close approximation to the average path length traveled by a charged particle as it slows down to rest, calculated in the continuous-slowing-down approximation. The extrapolated range is used as a measure of penetration depth in designing the detectors for electrons and planning therapeutic treatment and industrial irradiation by electron beams.

Different workers have studied the interactions of electrons with materials such as Berger and Seltzer[1] determined mean energy loss of electrons by collisions with atomic electrons and by bremsstrahlung and the mean range of forty materials for energies between 10 keV and 1000 MeV. Mukoyama[2] determined the range of electrons and positrons in detector materials in theregion above 70 keV. Calculation of the CSDA range of 50 keV to 100 MeV electrons in the absorbers of atomic numbers from 1 to 92 and in some detector materials, minerals, organic compounds and gaseous compounds has been conducted by Gupta and Gupta[3]. Batra and Sehgal[4] calculated ranges of electrons and positrons of kinetic energy ranging from 0.25 to 5.0 MeV in Al, Cu, Sn, Yb, and Pb. While

† Department of Physics, Punjabi University, Patiala, Punjab, India.
†† Yadwindra College of Engineering, Talwandi Saboo, Punjab, India.

electron ranges at energies above 10 keV are theoretically well described and can be found in tables given in Berger and Seltzer[5] and the ICRU Report No. 37 [6]. Pal et. al.[7] determined CSDA ranges of electrons and positrons in elemental and compound absorbers. Akar et. al.[8] calculated the CSDA range from the stopping power for low atomic number targets and biological compounds using the generalized oscillator strength model for incident electrons in the energy range 20 eV to 1 MeV. Tung and Kwei[9] calculated electron CSDA ranges in aluminum, copper, carbon, silver and gold using an electron gas statistical model.

A universal semiempirical formula for the extrapolated range was proposed by Tabata *et al.*[10]. Tabata *et al.*[11] obtained a systematic set of values of the extrapolated range for electrons of energies from 0.1 to 100 MeV in elemental media of atomic numbers from 4 to 92. These values showed mostly good agreement with the experimental data reported earlier by Tabata *et al.*[12]. Tabata et. al.[13] calculated the extrapolated range for compound materials of tissue-equivalent plastic, polymethyl methacrylate, solid water, water, air-equivalent plastic and air in the energy range of 0.1-100 MeV. Tabata et. al.[14] determined extrapolated ranges of electrons from transmission and projected-range straggling curves using the PENELOPE Monte Carlo code[15] for 0.1–50 MeV electrons incident on absorbers of atomic numbers between 4 and 92. Pimblott and Siebbeles[16] have evaluated CSDA ranges for non-relativistic electrons and positrons in liquid water.

ESTAR generates stopping powers and ranges for electrons which are the same as those tabulated in ICRU Report 37 for 72 materials at a standard grid of 81 kinetic energies between 10 keV and 1000 MeV. ESTAR can also calculate similar tables for any other element, compound or mixture. Furthermore it can calculate stopping powers at any set of kinetic energies between 1 keV and 10 GeV.

In the present work, to fill the gap in the available literature the CSDA and extrapolated range of electrons in some commonly used solvents (Diethylether, benzene, ethanol, glycerol, water) in the energy range of 0.01-100 MeV.

Theory

The expression for the calculation of CSDA range, r_o is given by Tabata et. al.[13] as:

$$r_o = \frac{c_1}{B}\left[\left(\ln\left(1 + c_2\tau_o^{c_3}\right)\Big/ c_2\right) - \left(c_4\tau_o^{c_5}\Big/\left(1 + c_6\tau_o\right)\right)\right]$$

where c_j (j=1, 2,…..6) are the constants for a given medium and B is called the stopping number, which is expressed as:

$$B = \ln\left(\tau_o \Big/ I + c_7\tau_o\right)^2 + \ln\left(1 + \tau_o/2\right)$$

where I is the mean excitation energy of the medium expressed in units of the rest energy of the electron and c_7 is a constant for a given medium.

The various expressions for c_k (k = 1, 2,…., 7) as a function of atomic number, Z and atomic weight, A of the medium has been expressed as follows:

$$c_1 = d_1 A / Z^{d_2} \quad ; \quad c_2 = d_3 Z^{d_4} \quad ; \quad c_3 = d_5 - d_6 Z$$

$$c_4 = d_7 - d_8 Z \quad ; \quad c_5 = d_9 - d_{10} Z \quad ; \quad c_6 = d_{11} / Z^{d_{12}} \quad ; \quad c_7 = d_{13} Z^{d_{14}}$$

where the d_l (l = 1, 2,. . . , 14) are the constants which are independent of medium and were obtained from the fits to the r_o data for each elemental medium.

The extrapolated range, r_{ex} can be expressed as the product of a detour factor, f_d and the CSDA range as:

$$r_{ex} = f_d . r_o$$

where f_d is a function of incident electron energy and the parameters that characterize the medium. It gives the contribution due to multiple scattering detours in the measurement of the extrapolated range.

The detour factor can be determined from the following empirical relation as:

$$f_d = 1 / \left[a_1 + a_2 / \left(1 + a_3 / \tau_o^{\,a_4} + a_5 \tau_o^{\,a_6} \right) \right]$$

where the symbols a_m (m = 1, 2,. . . , 6) denote the constants for a given medium.

The different expressions for a_m (m = 1, 2,. . . , 6) for the given medium are as follows:

$$a_1 = b_1 Z^{b_2} \quad ; \quad a_2 = b_3 + b_4 Z \quad ; \quad a_3 = b_5 Z^{b_6 - b_7 \ln Z}$$

$$a_4 = b_8 / Z^{b_9} \quad ; \quad a_5 = b_{10} Z^{b_{11} - b_{12} \ln Z} \quad ; \quad a_6 = b_{13} Z^{b_{14}}$$

where the symbols b_n (n = 1, 2,. . . , 14) denote the constants independent of medium which were obtained from the fits to the data on the ratio of r_{ex} / r_o for the each elemental medium.

RESULTS AND DISCUSSION

The CSDA ranges of electrons for the selected solvents are shown in Table 1. The values of CSDA range for water calculated using the present formulation are found to be in good agreement with the the reporting of ICRU 37[6], Berger and Seltzer[1] and Pimblott and Siebbeles[16]. The present results for other solvents are also in good agreement with the values obtained through ESTAR program[17] as shown in Table 1. The extrapolated range of electrons has also been obtained through the calculation of the detour factor for various solvents and has been shown in Table 2.

Table 1. The CSDA range of electrons in some commonly used solvents

Energy (MeV)	CSDA range (g/cm^2)				
	Diethylether ρ = 0.715 gml^{-1} Z_{eff} = 5.19	**Benzene ρ = 0.877 gml^{-1} Z_{eff} = 5.29**	**Ethanol ρ = 0.789 gml^{-1} Z_{eff} = 5.46**	**Glycerol ρ = 1.260 gml^{-1} Z_{eff} = 6.16**	**Water ρ = 0.997 gml^{-1} Z_{eff} = 6.60**
0.01	2.36 E-04	2.53 E-04	2.39 E-04	2.56 E-04	2.52 E-04
	*2.34 E-04	*2.52 E-04	*2.38 E-04	*2.56 E-04	*2.52 E-04
0.02	8.06 E-04	8.63 E-04	8.16 E-04	8.72 E-04	8.57 E-04
	*8.05 E-04	*8.63 E-04	*8.15 E-04	*8.72 E-04	*8.57 E-04
0.05	4.10 E-03	4.38 E-03	4.15 E-03	4.41 E-03	4.34 E-03
	*4.09 E-03	*4.37 E-03	*4.13 E-03	*4.40 E-03	*4.32 E-03
0.1	1.37 E-02	1.46 E-02	1.38 E-02	1.47 E-02	1.44 E-02
	*1.36 E-02	*1.45 E-02	*1.37 E-02	*1.46 E-02	*1.43 E-02
0.2	4.32 E-02	4.60 E-02	4.36 E-02	4.62 E-02	4.54 E-02
	*4.27 E-02	*4.55 E-02	*4.31 E-02	*4.57 E-02	*4.49 E-02
0.5	1.72 E-01	1.83 E-01	1.73 E-01	1.83 E-01	1.80 E-01
	*1.69 E-01	*1.80 E-01	*1.70 E-01	*1.80 E-01	*1.77 E-01
1	4.27 E-01	4.54 E-01	4.31 E-01	4.55 E-01	4.46 E-01
	*4.18 E-01	*4.46 E-01	*4.22 E-01	*4.47 E-01	*4.37 E-01
2	9.60 E-01	1.02 E+00	9.67 E-01	1.02 E+00	9.99 E-01
	*9.41 E-01	*1.00 E+00	*9.49 E+00	*1.01 E+00	*9.89 E+00
5	2.50 E+00	2.65 E+00	2.52 E+00	2.64 E+00	2.59 E+00
	*2.46 E+00	*2.62 E+00	*2.48 E+00	*2.62 E+00	*2.55 E+00
10	4.90 E+00	5.18 E+00	4.93 E+00	5.15 E+00	5.05 E+00
	*4.83 E+00	*5.12 E+00	*4.86 E+00	*5.12 E+00	*4.98 E+00
20	9.27 E+00	9.79 E+00	9.31 E+00	9.68 E+00	9.45 E+00
	*9.11 E+00	*9.65 E+00	*9.16 E+00	*9.62 E+00	*9.32 E+00
50	2.02 E+01	2.12 E+01	2.01 E+01	2.07 E+01	2.01 E+01
	*1.98 E+01	*2.09 E+01	*1.98 E+01	*2.06 E+01	*1.98 E+01
100	3.37 E+01	3.54 E+01	3.35 E+01	3.41 E+01	3.29 E+01
	*3.32 E+01	*3.50 E+01	*3.31 E+01	*3.40 E+01	*3.26 E+01

* CSDA range from ESTAR program

Table 2. The extrapolated range of electrons in some commonly used solvents

Energy (MeV)	Extrapolated range (g/cm^2)				
	Diethylether	**Benzene**	**Ethanol**	**Glycerol**	Water
0.01	2.32 E-04	2.46 E-04	2.29 E-04	2.31 E-04	2.21 E-04
0.02	6.98 E-04	7.43 E-04	6.97 E-04	7.22 E-04	6.98 E-04
0.05	3.52 E-03	3.75 E-03	3.52 E-03	3.63 E-03	3.51 E-03
0.1	1.18 E-02	1.25 E-02	1.18 E-02	1.21 E-02	1.17 E-02
0.2	3.74 E-02	3.96 E-02	3.73 E-02	3.83 E-02	3.70 E-02
0.5	1.50 E-01	1.59 E-01	1.49 E-01	1.53 E-01	1.48 E-01
1	3.77 E-01	3.99 E-01	3.76 E-01	3.87 E-01	3.73 E-01
2	8.63 E-01	9.13 E-01	8.62 E-01	8.86 E-01	8.57 E-01
5	2.35 E+00	2.48 E+00	2.35 E+00	2.42 E+00	2.35 E+00
10	4.84 E+00	5.11 E+00	4.85 E+00	5.01 E+00	4.87 E+00
20	9.82 E+00	1.04 E+01	9.84 E+00	1.02 E+01	9.89 E+00
50	2.40 E+01	2.52 E+01	2.40 E+01	2.46 E+01	2.39 E+01
100	4.41 E+01	4.63 E+01	4.39 E+01	4.46 E+01	4.30 E+01

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