Mass attenuation coefficients of beta particles in elements

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ABSTRACT

A new method to measure mass attenuation coefficient of β^- particles covering end point energies 0.318 to 2.28 MeV for elements H, C, O, Al, Cl, Cu and Ag from compounds and salts has been described. The measured mass attenuation coefficients of beta particles have been compared to the values given in previous work. A good agreement is found with (Thummel, 1974) empirical relation.

Keywords: Beta, Bragg's mixture rule, G. M. Counter, Mass attenuation coefficient.

INTRODUCTION

An accurate knowledge of beta particle (continuous energy electrons) mass attenuation coefficient (μ/ρ) is useful for dose calculation, radiation protection and bremsstrahlung studies in nuclear physics. The several measurements on mass attenuation coefficients and range-energy relation of β^- and β^+ particles for various absorber foils at different energies have been reported by various workers. (Katz and Penfold, 1952), (Takhar, 1967) investigate penetration of positron and electron in solids and liquids, (Mudhole, 1973) measures absorption coefficient of different thicknesses of metallic foils, (Nathuram *et al.*, 1981, 1982, 1987) has studied transmission and practical range of some metallic foils using 4π geometry setup (Baltakment, 1970) proposed the attenuation formula based on compilation of data for wide range energy given as

$$\frac{\mu}{\rho} = 0.008 Z^{0.28} E_m^{-[1.57-(Z/160)]} \text{ , cm}^2/\text{mg} \qquad (1)$$

(Thummel, 1974) empirical formula based on compellation of all available data as

$$\frac{\mu}{\rho} = 15.2 Z^{4/3} \frac{1}{A E_m^{1.485}} \text{ , cm}^2/\text{gm} \qquad (2)$$

where E_m is the maximum end point energy of beta particles in MeV, Z and A is atomic number and atomic weight of absorber. (Thontandarya, 1984) reported the semi-empirical formula for theoretical calculation of μ/ρ. (Bhupender Singh, 1987) has calculated μ/ρ of beta particles by considering the penetration theory of monoenergetic electrons and positrons in energy range 0.25 to 5.0 MeV for elemental absorber. (Burek 1996) and (Gurler, 2005) theoretically calculated μ/ρ of beta particles in elements. (C. Y. Yi. et al. 1998, 1999) calculated μ/ρ using semi-empirical transmission equation for monoenergetic electron and positron. Recently (Gurler, 2005) computed absorption coefficient based upon the analytical conclusion of beta emission energy spectra and range distribution of individual beta particles in Al, Cu, and Au.

In the present study, a new precision method to measure mass attenuation coefficient of β^- particles in element H, C, O, Al, Cl, Cu, and Ag using AR grade liquid compounds and water soluble salts is outlined here. The experimental values obtained are compared with measured and calculated values given in previous work.

MATERIALS AND METHODS

The experiments were performed on Geiger-Muller counting system. A plastic disk type beta sources having active area of 1 cm diameter was allowed to incident on end window G.M tube having a 3.5 cm diameter of aluminized mylar window of 1 mg/cm^2 surface density. The two lead collimator slits of internal diameter 1.0 cm and 1.4 cm are kept above source and below the G. M. tube. Distance between source and G. M. window was 5 cm. The borosil (composition B: 0.040064, O: 0.539562, Na: 0.028191, Al: 0.011644, Si: 0.377220, K: 0.03321) glass container having internal radius (r) 1.1555 cm and material density 2.23 gm/cm^3 is kept above 1 cm from source. The effective solid angle of setup is 0.7 steradian. Liquid container and burette are sealed with butter paper and connected to each other by 0.13 cm polyethylene micro tube to prevent evaporation of liquid compounds. The whole assembly was enclosed in a lead castle. A schematic of the experimental setup is shown in Fig.1. The absorber thickness was increased in steps by adding liquid compound from burette and corresponding transmitted particles were counted in preset count mode for 1000 sec at room temperature. The counting rates were corrected for background and dead time (t_d) for each energy sources. A homogeneous aqueous solution of 5 gram (m_s) of salt dissolved in 25 ml (m_w) distilled water used for salt attenuation.

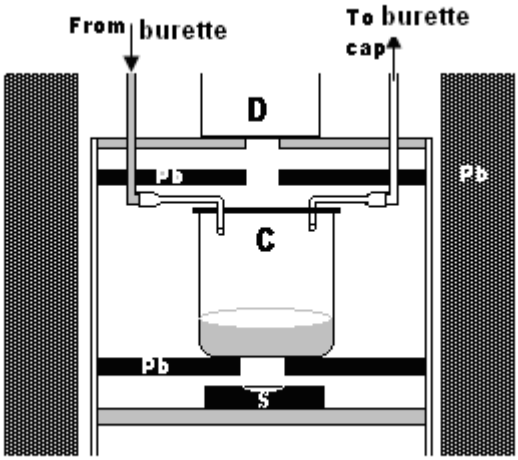


Fig. 1 Schematic of experimental setup for attenuation measurement. D - G.M. tube, S - Beta source, Pb - Lead collimator, C – Container.

The β^- emitters ^{60}Co (0.318), ^{90}Sr (0.546), ^{204}Tl (0.770) and ^{90}Y (2.28) having activity 0.3 - 0.5 μCi are used for this measurement where the number in bracket indicates the end point beta energy in MeV.

Mass attenuation coefficients

Theoretically mass attenuation coefficient of a compound is calculated from the elemental coefficients given by Bragg's mixture rule as

$$\left[\frac{\mu}{\rho}\right]_{comp} = \sum_{e=1}^{n} w_e \left(\frac{\mu}{\rho}\right)_e \qquad (3)$$

where $(\mu/\rho)_e$, w_e are the mass attenuation coefficients and weighting factors respectively of the constituent elements of the compound.

The intensity of beta particles varies exponentially with the thickness of the absorber is written as,

$$\left[\frac{\mu}{\rho}\right]_{Expt} = \frac{1}{\rho t} \ln\left(\frac{N_0}{N}\right) = \frac{\pi r^2}{m} \ln\left(\frac{N_0}{N}\right) \quad (4)$$

where N, N_0 are the count rates with and without container and absorber, ρ is density (gm/cm^3) and t is height (cm) of absorber in container. For experimental convenience mass thickness ρt is converted into mass. The approximate computation of μ/ρ is based on the assumption that over a limited region. Graph of $ln(N_o/N)$ versus m gives slope equal to experimental mass attenuation coefficient.

Absorption of beta particles is partially by compound as well as thin base of borosil container. Therefore equation (3) for binary absorber is rewritten as

$$\left[\frac{\mu}{\rho}\right]_{EXPT} = \left[\frac{\mu}{\rho}\right]_C + \frac{m_B}{m_C + m_B}\left[\left(\frac{\mu}{\rho}\right)_B - \left(\frac{\mu}{\rho}\right)_C\right] \quad (5)$$

where m_C and m_B (0.4394 gm) stands for mass of compound, base of container. Plot of $(\mu/\rho)_{EXPT}$ versus (m_B/m_C+m_B) gives slope equal to $[(\mu/\rho)_B-(\mu/\rho)_C]$ and intercept $(\mu/\rho)_C$ for μ/ρ of salt solution, suffix c replaced to s+w and m_c to m_s+m_w in equation (5).

The μ/ρ for elements are obtained by rewriting equation (3) for compounds acetone, 1-hexanol and 1-octanol together having a system of three simultaneous equations in matrix form as

$$\left(\frac{\mu}{\rho}\right)_{comp} = w\left(\frac{\mu}{\rho}\right)_{ele} \quad (6)$$

Representing μ/ρ of acetone, 1-hexanol and 1-octanol as components of a column vector $(\mu/\rho)_c$ and $(\mu/\rho)_e$ for the elements H, C and O. W is 3x3 matrix of weighting factors of H, C and O in the compounds given by

$$w = \begin{bmatrix} H & C & O \\ w_{11} & w_{12} & w_{13} \\ w_{21} & w_{22} & w_{23} \\ w_{31} & w_{32} & w_{33} \end{bmatrix} = \begin{bmatrix} 0.104123 & 0.620409 & 0.275468 \\ 0.138101 & 0.705315 & 0.156583 \\ 0.139310 & 0.737838 & 0.122853 \end{bmatrix}$$

Multiplying equation (6) by W^{-1} gives

$$\left(\frac{\mu}{\rho}\right)_e = w^{-1}\left(\frac{\mu}{\rho}\right)_C \quad (7)$$

$$W^{-1} = \begin{bmatrix} -28.8121 & 126.7185 & -96.9064 \\ 4.8355 & -25.5205 & 21.6850 \\ 3.6302 & 9.5796 & -12.2098 \end{bmatrix}$$

where W^{-1} is the inverse matrix of W.

The μ/ρ for elements Al, Cl, Cu and Ag are obtained by substituting μ/ρ values of element H, C and O in $(\mu/\rho)_{s+W}$ by using equation (5) and (3). Table 1 and 2 shows experimental μ/ρ values for compound, salt and elements respectively.

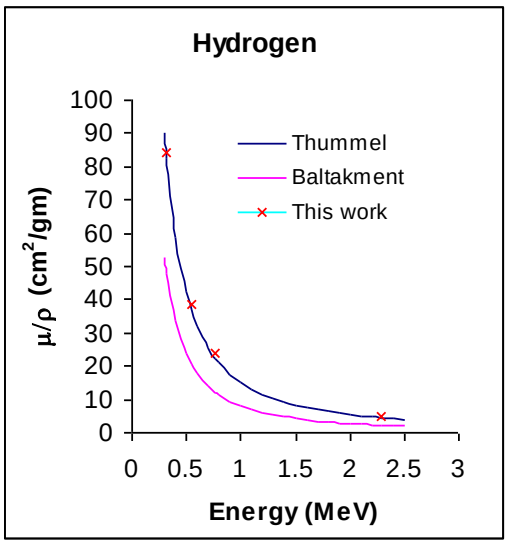
RESULT AND DISCUSSION

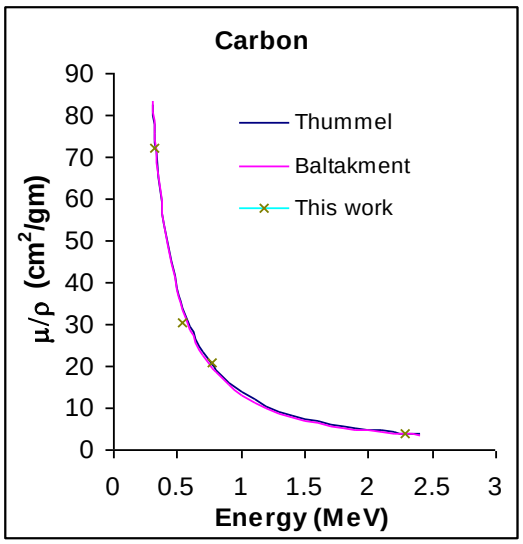
The mass attenuation coefficients measured in this work have been given in Fig. 2 for H, C, O, Al, Cl, Cu and Ag together with values in literature. The measurement of mass attenuation coefficient for β^- particles end point energies 0.318 to 2.280 MeV in elements H, C, O, Al, Cl, Cu and Ag. The present measurements with published values are shown in Fig. 2. They are in the good agreement with (Thummel, 1974) and satisfactory with (Thontadarya, 1984 & 1971); (Nathuram, 1982) measured values. However a higher deviation in μ/ρ values for energy 0.318 MeV. The deviation rather large is because of statistical variation in experimental observations at some energies and the different geometrical setup adopted by various workers.

The measurement of mass attenuation coefficient of beta particles in elements from compounds and water soluble salts explores the expected validity of exponential law and mixture rule provides a direct method for determination of elemental μ/ρ from liquid compounds and water soluble salts without obtaining them in pure crystalline form. The present method can also be extended for measurement of mass attenuation coefficient of remaining elements.

Table 1. Measured mass attenuation coefficient (cm^2/gm) of various beta particle energies in compounds and salts.

Compound/salt	Beta particle energy			
	0.318 MeV t_d=240 µSec	0.546 MeV t_d=44 µSec	0.770 MeV t_d= 20 µSec	2.280 MeV t_d = 11.28 µSec
Acetone	76.2590	33.1836	21.8783	4.1010
1-Hexanol	75.4570	32.6607	21.6540	4.1107
1-Octanol	75.1296	32.4447	21.5643	4.1039
Carbon tetrachloride	97.8340	47.4039	27.5900	5.1085
Aluminium chloride	98.4212	48.4324	27.6098	5.2493
Copper chloride	99.4712	49.4981	29.8452	5.9172
Silver chloride	111.9731	54.8862	33.6604	6.5531





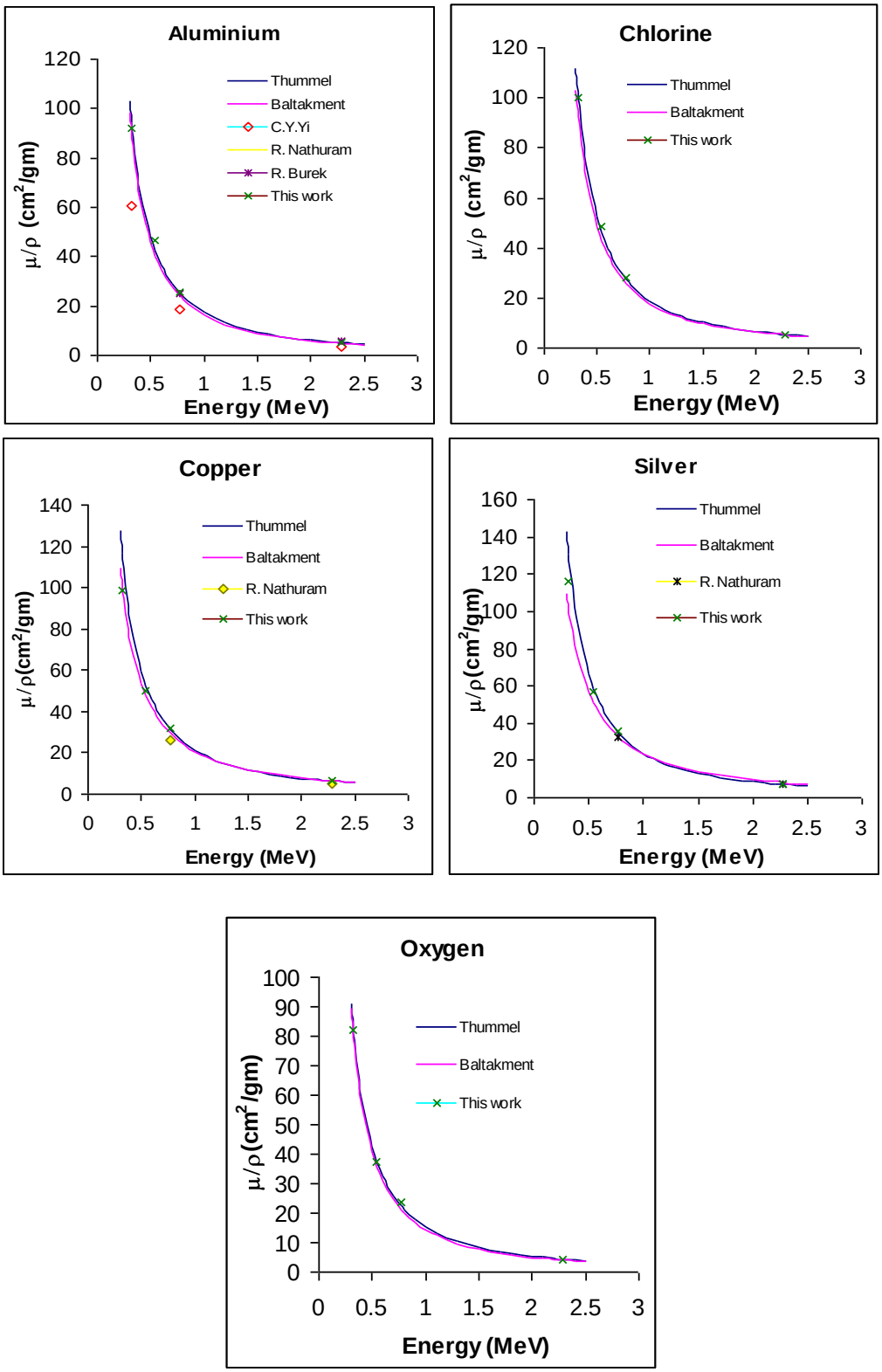


Fig. 2 Mass attenuation of β^- particles for hydrogen, carbon, oxygen, aluminium, chlorine, copper and silver.

Table 2. Comparison of measured elemental mass attenuation coefficient (cm^2/gm) of various beta particles energies with some calculated and measured values. Percentage deviation are shown with Thummel[8] only.

	Mass attenuation coefficient in cm^2/gm and Beta particle energy in MeV							
	0.318 MeV		0.546 MeV		0.77 MeV		2.28 MeV	
Elements	Calculated	Measured	Calculated	Measured	Calculated	Measured	Calculated	Measured
Hydrogen	82.6650[8]	84.0769	37.0421[8]	38.5266	22.2325[8]	23.884	4.4350[8]	5.04436
	47.9921[4]		20.6089[4]		12.0390[4]		2.2048[4]	
% deviation		-1.7079		-4.0077		-7.4285		-13.7400
Carbon	75.6302[8]	72.2369	33.8897[8]	30.5059	20.3405[8]	20.7939	4.0576[8]	3.9174
	76.4721[4]		33.3983[4]		19.7208[4]		3.7363[4]	
% deviation		4.4867		9.9866		-2.2293		3.4546
Oxygen	83.3233[8]	82.3622	37.3370[8]	37.1946	22.4095[8]	23.5624	4.4703[8]	4.1579
	81.7083[4]		35.9271[4]		21.3054[4]		4.0916[4]	
% deviation		1.15358		0.3814		-5.1447		6.9885
Aluminum	94.3894[8]	92.1838	42.2957[8]	46.8412	25.3857[8]	25.4176	5.0640[8]	5.4062
	90.3141[4]	86.9000 [5]	40.3876[4]	41.1000[9]	24.2092[4]	24.8200[11]	4.8097[4]	5.0000[10]
	82.5000[15]	60.7000[13]	35.9000[15]		22.6000[15]	18.5000[13]	5.8000[15]	5.5700[11]
			37.1500[17]		21.9200[17]		4.2300[17]	3.5000[13]
% deviation		2.3366		-10.7469		-0.1258		-6.7574
Chlorine	102.7271[8]	100.004	46.0318[8]	48.8361	27.6281[8]	28.1661	5.5113[8]	5.2095
	94.6102[4]		42.8845[4]		25.9278[4]		5.2928[4]	
% deviation		2.6508		-6.0920		-1.9474		5.4764
Copper	116.8194[8]	98.8766	52.3466[8]	50.2369	31.4182[8]	31.7189	6.2674[8]	6.70371
	100.8244[4]	100.1[5]	47.5921[4]	43.9000[9]	29.5255[4]	26.2000[10]	6.5385[4]	5.9000[10]
	98.2000[15]		38.3000[15]		26.6000[15]		6.7000[15]	
			46.5400[17]		28.4100[17]		6.3500[17]	
% deviation		15.3594		4.0302		0.9572		-7.0160
Silver	131.0094[8]	115.9056	58.7051[8]	56.8739	35.2345[8]	35.4655	7.0287[8]	6.9719
	101.4623[4]		50.8962[4]		32.8203[4]	32.8000[10]	8.2122[4]	7.3000[10]
% deviation		11.5287		3.1192		-0.6655		0.8077

[4.] Baltakments (1970), [5,11.] Thontadarya (1971 and 1984), [8]Thummel (1974), [9,10,13.] Nathuram (1981,1982 and 1987), [15.] C. Y. Yi (1998), [17.] O. Guler, S. Yacin (2005)

ACKNOWLEDGMENT

The author very much thankful to University Grant Commission, New Delhi for financial support under minor research grant and wishes to express his appreciation to Mr. N. N. Sangam for their technical assistant.

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