Determination of Physical Parameters of Solid State Materials by γ- Ray Attenuation

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ABSTRACT-

Experimental study of γ-ray attenuation at different energies viz. Am (0.0595MeV), Cs (0.66MeV), Co (1.173MeV & 1.332MeV) leads to the evaluation of mass attenuation coefficients (μ_m) of solid state alkali halides, at each energy. The theoretical values of mass attenuation coefficients of the materials are calculated by mixture rule. Using experimental and calculated values of mass attenuation coefficients, the photon interaction parameters of the materials are evaluated, and are reported for the first time. The comparison of experimentally determined values with the calculated values are in good agreement.

KEY WORDS: *Photon interaction parameters, alkali halides, Pellets, X-Com.*

INTRODUCTION

The beauty of application of γ-ray principle lies in the fact that it can be absorbed by materials. Knowledge of radiation absorption mechanism in materials is necessary for keeping radiation within the desired limit to avoid hazards and also important in radiation medicine, biology, nuclear engineering and space technology. Mass attenuation coefficient of a substance signifies how strongly radiation is absorbed or scattered by it at a given wavelength, per unit mass. Other photon interaction parameters can be obtained using mass attenuation coefficient and they helps in getting the knowledge of physical properties of composite materials and compounds. There is a dire need of systematic and precise studies of photon interaction parameters of different shielding materials for γ-radiation. These studies will be of utmost important for the effective and harmless utilization of X-rays and γ-rays in fields such as radiation dosimetry etc;- Experimental measurements of the mass attenuation coefficients of materials have been carried out by various researchers. The recent studies performed on the attenuation coefficients and photoelectric effect on rare earth elements using ^{241}Am γ- rays [1] and Sahin [2] for PbO, barite and some boron ores. Abdel-Rahman et al. [3] determined γ-ray attenuation coefficients for perspex, bakelite, paraffin, Al, Cu, Pb and Hg at three different γ-ray energies 59.54, 661.6 and 1332.5 keV. Hine [4] introduced the concept of effective atomic number for compounds and mixtures. The effective atomic number represents the attenuation of γ-rays in a complex medium and useful for the calculation of the dose in radiation therapy [5]. Kumar and Reddy [6] carried out studies to determine the Z_{eff} values of composite materials. The author [7, 8] has determined the photon interaction parameters of different compounds for multienergetic γ-photons. Though LiI, CsF and RbF have wide applications in different fields, in literature, there are almost no reports on photon interaction parameters of these compounds. This prompted the author to go ahead with the present investigation.

EXPERIMENTAL METHOD

A die set and hydraulic press have been used to prepare pellets of alkali halide powders (Table-I) of high purities in the present study.

Transmission experiment with the narrow beam has been conducted by the experimental setup described (Fig. 1) [7] to detect the γ-ray attenuation in the pellet, and to determine its mass attenuation coefficient.

The sample holder along with the sample is placed between the source and the detector ensuring a proper alignment of sample with collimation 6mm on either side. The distances between γ-source, sample was 8cm and sample, detector was 6cm. The pellet was irradiated by γ–energies emitted by 10 mCi ^{241}Am, 30 mci ^{137}Cs and 11.73 μCi ^{60}Co radioactive sources respectively Intensities of the photons transmitted were recorded for a duration of 10 minutes, under the photo peaks of Gaussian distribution. The peak areas have been calculated from the spectrum obtained for each measurement. The γ- ray counts for every energy with sample (I) and without sample (I_o) were detected and recorded six times (average value was taken in calculations) using a NaI (Tl) scintillation detector coupled to photo multiplier tube (PMT) mounted on a coaxial in-line pre-amplifier. The amplified pulse is then fed to the Multi-Channel Analyzer (MCA), which converts the analog signal into a digital number through an analog to digital converter (ADC). The procedure is repeated with each pellet.

ANALYSIS OF THE DATA

Analysis of the data has been carried out using relations in section 3 [7, 8]. The uncertainty in the measured parameters depends on uncertainty in the measurement of the mass attenuation coefficient, which has been calculated using the expression

$$\Delta(\mu_m) = \frac{1}{\rho l}\left[\left(\frac{\Delta I_0}{I}\right)^2 + \left(\frac{\Delta I}{I}\right)^2 + \left(\ln\frac{I_o}{I}\right)^2 + \left(\frac{\Delta l}{l}\right)^2\right]^{1/2} \quad (1)$$

where ΔI_0, ΔI and Δl are the errors in the intensities of I_0, I and thickness l respectively. Theoretical values for the mass attenuation coefficients are obtained by Win Xcom program [9].

RESULTS AND DISCUSSION

The factors affect the value of mass attenuation coefficient are incident photon energy and the chemical content of the compound. The Mass attenuation coefficient (μ_m) values of alkali halides were determined experimentally for γ-photons of different energies. The experimental values are compared (Table-II) with theoretical values calculated by using semi empirical expressions (1, 2 and 3) of section-3 [7] and with the X-Com values, found in good agreement. Mass attenuation coefficient values of all materials in the present study decrease with the increase in photon energy, as the probability of absorption reduces with increasing incident photon energies results in the increase in the transmission of photons. Dependence of μ_m in alkali halides on photon energy is given in Fig. 1. The experimental values of halides tend to be slightly smaller than theoretical values. Because the total experimental uncertainty of mass attenuation coefficient values depend on the uncertainties of peak area evaluation, mass thickness measurements, experimental system, counting statistics, and efficiency errors and so on [Eqn. (1)]. Linear attenuation coefficients (μ_l), total photon interaction cross-sections (σ_t and σ_e), effective atomic number (Z_{eff}), effective electron number (N_{eff}) and photon mean free path (λ) of alkali halides at different photon energies are calculated (Table–II), with the mass attenuation coefficients using expressions (4-9) (section-3 [7]).

The dependence of σ_τ and σ_e on the photon energy (Fig. 2 and Fig.3) is dominant at low energies, and negligible at high energies as the mass attenuation coefficients reduces with the increase in incident photon energies The Z_{eff} and the N_{eff} for a compound remains constant and are independent of photon energy (Table-II). The electron density is closely related to the effective atomic number and hence the qualitative energy dependence is same.

The photon mean free path (λ) is increasing with the photon energy (Fig.4) due to decrease in the probability of interaction of photons in the material with the increase in energy.

CONCLUSIONS

A study of γ-photon attenuation at different energies have been carried out in alkali halides by transmission beam method, to determine (μ_m) and related parameters (σ_t, σ_e, Z_{eff}, N_{eff} and λ). We understand that the (μ_m) is useful and sensitive physical quantity to determine the (Z_{eff}) and (N_{eff}) of a compound. The (μ_m) values of alkali halides decreases with the increase in photon energy. The variation of (σ_t and σ_e) with energy is same as the mass attenuation coefficient. The photon interaction parameters of alkali halides at different γ- energies have been reported for the first time.

Table-I

Sample Pellet	Element	Composition in %	Mass of sample powder (gm)	Pellet thickness (cm)	pressure applied (psi)
LiI	Li	5.18	20.0	1.45	2300
	I	94.82			
CsF	Cs	87.49	25.0	1.30	2100
	F	12.51			
RbF	Rb	81.81	27	1.50	2000
	F	18.19			

μ, μ_l, σ_t , σ_e, Z_{eff} , N_{eff}. And λ values (comparison between experimental, theoretical and X-Com) of alkali halides at different γ-energies

Table-II

Energy	**Am 0.0595MeV**			**Cs 0.66MeV**			**Co1.173MeV**			**Co 1.332MeV**		
Sample	X-Com value	Empirical value	Expt. Value	X-Com value	Empirical value	Expt. Value	X-Com value	Empirical value	Expt. Value	X-Com value	Empirical value	Expt. Value
μ_m [10^{-3} m^2kg^{-1}]												
LiI	3000.4	3000.7	2999	7.66	7.66	7.65	5.28	5.28	5.28	4.93	4.93	4.92
CsF	3436.4	3436.4	3434	7.75	7.74	7.75	5.34	5.35	5.32	4.97	4.97	4.96
RbF	899.21	899.2	897.4	7.15	7.15	7.14	5.29	5.32	5.28	4.95	4.95	4.95
μ_l [m^{-1}]												
LiI	3000.43	3000.69	2998.8	31.23	31.23	31.22	21.56	21.56	21.54	20.1	20.1	20.08
CsF	3436.38	3436.36	3434.1	35.98	35.9	35.96	24.75	24.8	24.68	23.05	23.06	23.02
RbF	899.21	899.204	897.43	25.42	25.42	25.41	18.81	18.93	18.78	17.61	17.61	17.6
σ_t [10^{-25} barn/atom]												
LiI	817.12	817.19	816.68	8.51	8.51	8.5	5.87	5.87	5.87	5.47	5.47	5.47
CsF	933.92	933.91	933.29	9.78	9.76	9.77	6.73	6.74	6.71	6.26	6.27	6.26
RbF	219.23	219.23	218.8	6.2	6.2	6.19	4.59	4.61	4.58	4.29	4.29	4.29
Energy	**Am 0.0595MeV**			**Cs 0.66MeV**			**Co1.173MeV**			**Co 1.332MeV**		
Sample	**X-Com value**	**Empirical value**	**Expt. Value**	**X-Com value**	**Empirical value**	**Expt. Value**	**X-Com value**	**Empirical value**	**Expt. Value**	**X-Com value**	**Empirical value**	**Expt. Value**
σ_e[10^{-26} barn/atom]												
LiI	287.4	287.5	287.3	2.99	2.99	2.99	2.07	2.07	2.06	1.93	1.93	1.92
CsF	278.3	278.3	278.2	2.91	2.91	2.91	2.01	2.01	2	1.87	1.87	1.86
RbF	92.78	92.78	92.59	2.62	2.62	2.62	1.94	1.95	1.94	1.82	1.82	1.82
Z_{eff}												
LiI	28.43	28.43	28.43	28.43	28.43	28.43	28.43	28.43	28.43	28.43	28.43	28.43
CsF	33.55	33.55	33.55	33.55	33.55	33.55	33.55	33.55	33.55	33.55	33.55	33.55
RbF	23.63	23.63	23.63	23.63	23.63	23.63	23.63	23.63	23.63	23.63	23.63	23.63
N_{eff} [10^{23} electron/g]												

LiCl	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56	2.56
LiBr	2.66	2.66	2.66	2.66	2.66	2.66	2.66	2.66	2.66	2.66	2.66	2.66
LiF	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72
λ [10^{-2} m]												
LiI	0.033	0.033	0.033	3.2	3.2	3.2	4.64	4.64	4.64	4.97	4.97	4.98
CsF	0.029	0.029	0.029	2.78	2.79	2.78	4.04	4.03	4.05	4.34	4.34	4.34
RbF	0.111	0.111	0.111	3.93	3.93	3.94	5.32	5.28	5.32	5.68	5.68	5.68

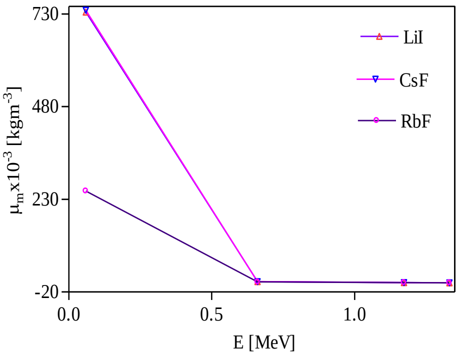

Fig.1 μ_m versus energy

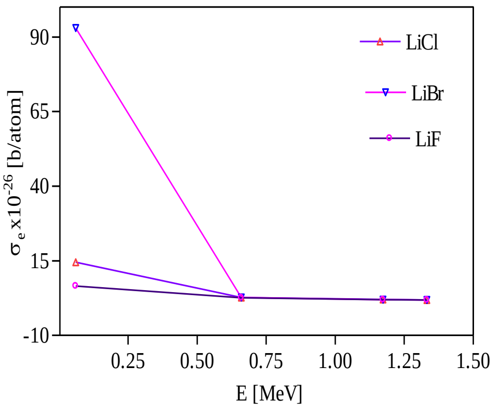

Fig. 3 σ_e verses energy

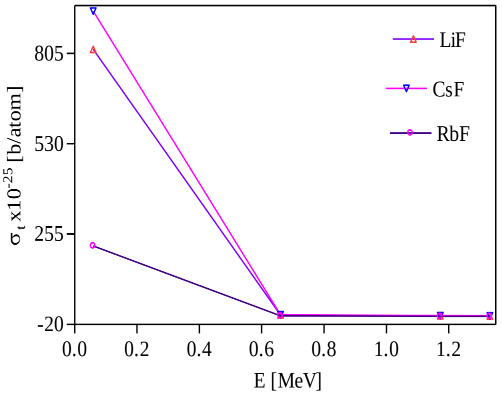

Fig.2 σ_τ versus energy

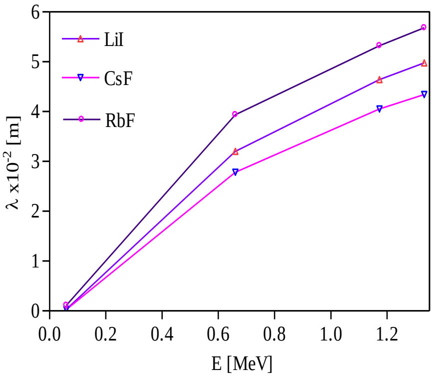

Fig. 4 λ verses energy

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