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GAMMA RAY INTERACTION STUDIES ON SOME SHAPE MEMORY ALLOYS IN THE ENERGY RANGE 122 KEV TO 1330 KEV

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Abstract

In this paper, we have been calculated and measured the attenuation cross section parameters of some shape memory alloys in the energy range 122 keV to 1330 keV. From the present study, it is observed that there is good agreement between experimental and theoretical values and the variation of obtained values of all parameters strongly depends on the photon energy; it decreases or increases due to chemical composition and density of the sample material. All samples have been studied extensively using WinXCOM program and transmission curve shows that the variation of all sample materials initially decreases with increasing photon energy. The present study can be useful in radiation therapy, medical, aerospace, robotics, engineering and many technological applications.

Keywords: *Mass attenuation coefficients, total atomic cross section, total electronic cross section*

1. Introduction:

The data on absorption and penetration of X-rays/ gamma rays photon interaction with matter is great significant in many fields such as medical, biological and industrial area. The study of absorption and scattering of gamma rays in the compound materials has become an interesting and exciting field of research (Manohara et al., 2007). There is a plethora in this particular field and a large number of photon attenuation measurements and calculations have been made for diverse materials and the attenuation coefficient has been studied as a function of various parameters. The mass attenuation coefficient, total atomic cross section and total electronic cross section are basic parameter for penetration and diffusion of x-ray or gamma ray in extended media. The accurate values of the mass attenuation coefficient for X-ray and gamma ray in different materials are very significant in various fields such as medical, agriculture, industrial, biological, nuclear radiation physics and radiation dosimetry (Han and Demir ; 2009). The mass attenuation coefficient is key parameter in the primary physics and many applied fields. Mass attenuation coefficient (μ_m) is a measure of the probability of interaction that occurs between incident photons and samples mass per unit area. Mass attenuation coefficient is needed to understand the diffusion and transmission of

X-ray and γ- ray in the material (Manohara and Hanagodimath; 2007). Number of the authors were represented the table in the form of tabulation for all elements and developed new computer program such as WinXCOM program (Hubbell; 1982, Hubbell and Seltzer; 1995, Berger and Hubbell; 1987, Gerward et al.; 2001). Some of the research papers are available on experimental and theoretical study of mass attenuation coefficient (μ_m) values in a variety of elements and compounds/mixtures. Mass attenuation coefficient data can be used for the determination of several parameters such as effective atomic numbers (Z_{eff}), effective electron density (N_{eff}), molar extinction coefficient (ε), mass energy absorption coefficient ($\mu_{en/\rho}$), etc. of compound materials (Kore et al.; 2016, Pawar and Bichile; 2013, Ladhaf and Pawar; 2015, Gaikwad et al.; 2016, Awasarmol et al.; 2017a, Awasarmol et al.; 2017b, Awasarmol; 2017c, Awasarmol et al.; 2017d).

Shape Memory Alloy’s (SMA’s) are the most significant branch from the smart / intelligence materials (Satish et al.; 2013). During the last decade smart materials and structures have received increasing attention because due to their huge technological and scientific consequence. SMA’s are basically functional materials which exhibit peculiar thermo mechanical properties such as shape memory effect and the super elasticity. These properties are significant as a reversible thermo elastic martensitic transformation occurring at the solid state. SMA alloys are most commonly used in commercial fields such as biomedical (i.e. stents, surgical tools); sensor/actuator (valves); coupling (i.e. electric fastener, pipe fastener); sport, antennas, gadgets, manufactures etc (Kumar and Lagoudas ; 2008).

In literature, we observed that the no experimental data is available on the study of some shape memory alloys. The aim of the present study, we have been measured the mass attenuation coefficient of some shape memory alloys and related parameters in the energy region 122 keV to 1330 keV by using the transmission method and compared with Win XCOM data.

2. Theoretical Analysis:

2.1 Calculation of mass attenuation coefficient (μ_m)

The mass attenuation coefficients for the compound materials and energies are determined by the transmission experiment. This process described by the following equation:

$$I = I_0 \exp(-\mu_m t) \qquad (1)$$

where I_0 and I are the unattenuated and attenuated photon intensities respectively, μ_m (cm^2gm^{-1}) is mass attenuation coefficient of the material and t (g/cm^2) is the sample thickness.

The photon mass attenuation coefficient for compound or mixture of element is given by mixture rule:

$$\mu_m = \sum iW_i(\mu_m)_i \qquad (2)$$

where W_i and $(\mu_m)_i$ are the weight fraction and mass attenuation coefficient of the ith constituent element, respectively. For a chemical compounds, the fraction by weight (W_i) is represented by following expression:

$$W_i = \frac{n_i A_i}{\sum_j n_j A_j} \qquad (3)$$

where A_i is the atomic weight of the ith element, n_i is the number of formula units, $\sum_j n_j$ is the total number of atoms present in the molecular formula and A_j is the molecular weight of the jth constituent elements.

2.2 Calculation of total atomic cross section ($\sigma_{t,a}$)

The total atomic cross section can be derived by following equation:

$$\sigma_{t,a} = \frac{1}{N_A}\frac{\mu_m}{\sum_i W_i / A_i} \qquad (4)$$

where N_A is the Avogadro’s number, μ_m is the mass attenuation coefficient.

2.3 Calculation of total electronic cross section ($\sigma_{t,el}$)

The total electronic cross section is determined by,

$$\sigma_{t,el} = \frac{1}{N_A}\sum_i \frac{f_i A_i}{Z_i}(\mu_m)_i \qquad (5)$$

where f_i is the number fraction of atoms of element i and Z_i is the atomic number of the ith element in the mixture or compound.

3. Experimental details

In this study, we have been carried out some attenuation cross section parameter by the transmission method of the narrow beam good geometry setup. The schematic diagram as shown in Fig. 1. In this experiment we have been used six radioactive sources such as ^{57}Co’ ^{133}Ba, ^{137}Cs, ^{54}Mn^{60}, Co, and ^{22}Na. All these radioactive sources are provided by Bhabha Atomic Research Center, Mumbai, for the experimental work. These radioactive sources emitted gamma ray photon energies at 122, 356, 511, 662, 840, 1170, 1275 and 1330 keV.

The radioactive sources were collimated and detected by (2″×2″) NaI (Tl) scintillation detector with resolution 8.2% at 662 keV and the signals at the detector were amplified and analyzed by the 8K multichannel analyzer. For preparation of the sample in the form of pallet and the sample was weighed in a sensitive digital balance and having a good accuracy of measurements about 0.001 mg and the plastic container was used as sample holder, and attenuation of a photon by unfilled container were found to be negligible (Pawar and Bichile; 2013). The weighing samples five time to get more accuracy. The mean of this set value was considered to be the mass of the sample. The transmitted intensity of photo peak was measured to minimize both contributions of small angle and multiple scattering within the full width at half maxima. For more accuracy, a thickness of the sample was selected as per Creagh (1987) criteria $2 < \ln (I0 /I) < 4$. More information about the experimental arrangement has been reported in our previous work by (Awasarmol et al.; 2017a, Awasarmol et al.; 2017b, Awasarmol; 2017c, Awasarmol et al.; 2017d).

4. Results and discussion

In this study, the theoretical and experimental values of mass attenuation coefficient (μ_m), total atomic cross section ($\sigma_{t,a}$) and total electronic cross section ($\sigma_{t,el}$) were measured at 122 keV to 1330 keV photon energies for some shape memory alloys i.e. cast Iron, Nitinol, Babit Metal, Stelite, Amalgam carried out by NaI (Tl) scintillation detector with a well collimated narrow beam good geometry setup. Theoretically and experimentally measured values of the mass attenuation coefficients (μ_m) for five samples tabulated in Table 1 and variation with energy (E) is displayed in Fig. 2. From Fig. 2 it is clearly seen that the variation of μ_m values decreases with increasing photon energy. The experimental values of μ_m agree with theoretical values calculated using the WinXCOM program based on the mixture rule. Measured total atomic cross section ($\sigma_{t, a}$) and total electronic cross section ($\sigma_{t, el}$) for the studied shape memory alloys are listed in Tables 2 and 3 respectively. The typical plots of $\sigma_{t, a}$ and $\sigma_{t, el}$ versus photon energy (E) are displayed in Figs. 3 and 4 respectively. From Figs. 3 and 4 the behavior of $\sigma_{t, a}$ and $\sigma_{t, el}$ with photon energy (E) is almost similar to that of μ_m. The variation of the all attenuation parameters were systematically studied in the given photon energy region.

5. Conclusion

In this research μ_m were investigated to get sufficient information about mass attenuation coefficients (μ_m), total atomic cross section ($\sigma_{t, a}$), and total electronic cross section ($\sigma_{t,\ el}$) for shape memory alloys materials and it has been observed that the present data on μ_m values and other parameters are very useful in biomedical**,** medical and biological, sensor/actuator, and other applications. In this paper, we reported that the experimental data on (μ_m), ($\sigma_{t,\ a}$), and ($\sigma_{t,\ el}$) of shape memory alloys materials at different photon energy range. Mass attenuation coefficient and other parameters of all samples have been calculated at 122 keV to 1330 keV photon energies. This study concludes that any compound material depends on its chemical composition, density, and concentration of the elements that it contains

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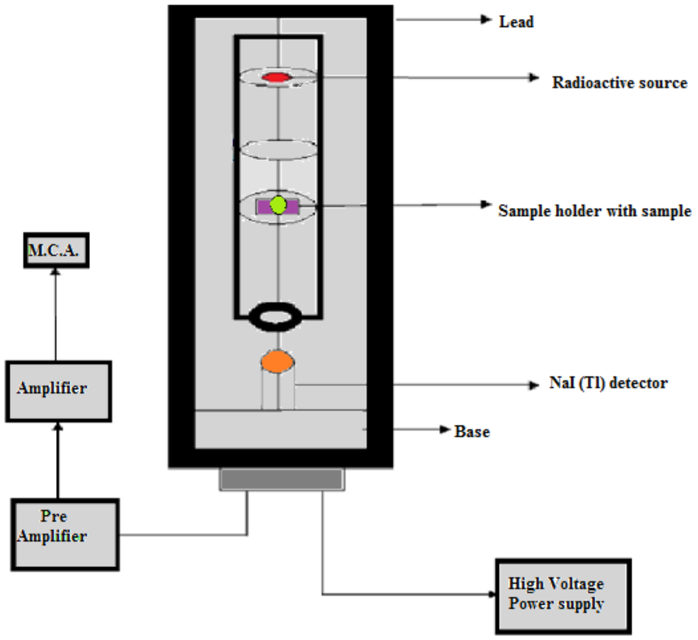

Fig. 1 Schematic set up of NaI (Tl) scintillation detector.

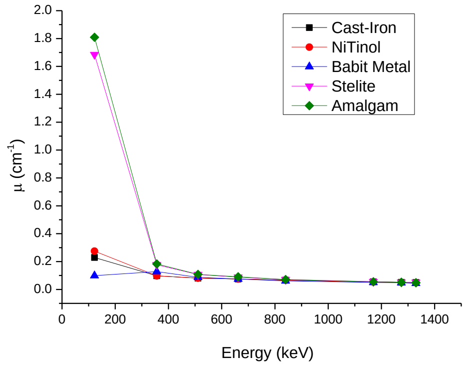

Fig. 2 Mass attenuation coefficients of shape memory alloys.

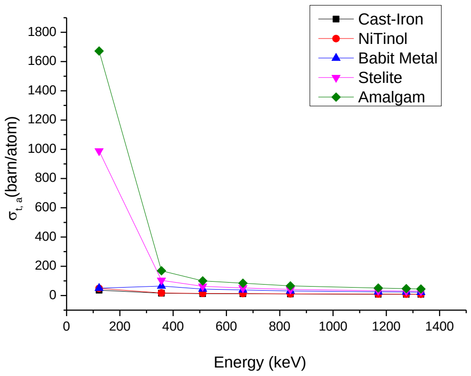

Fig. 3 Total atomic cross section of shape memory alloys.

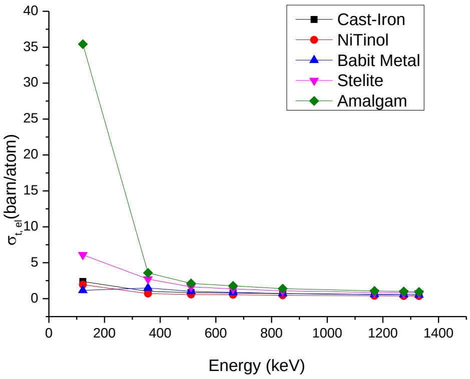

Fig. 4 Total electronic cross section of shape memory alloys.

Table 1. Mass attenuation coefficients of shape memory alloys.

Energy	Cast-Iron		NiTinol		Babit Metal		Stelite		Amalgam	
	Exp.	Theo.	Exp.	Theo.	Exp.	Theo.	Exp.	Theo.	Exp.	Theo.
122	0.229	0.231	0.275	0.281	0.0991	0.996	1.685	1.706	1.809	1.816
356	0.098	0.101	0.098	0.102	0.128	0.133	0.177	0.183	0.183	0.189
511	0.081	0.085	0.081	0.084	0.087	0.091	0.107	0.111	0.108	0.113
662	0.075	0.078	0.075	0.077	0.075	0.08	0.088	0.093	0.091	0.094
840	0.067	0.068	0.066	0.067	0.061	0.066	0.071	0.074	0.071	0.073
1170	0.055	0.057	0.054	0.056	0.05	0.054	0.056	0.058	0.055	0.058
1275	0.051	0.055	0.051	0.053	0.048	0.051	0.052	0.054	0.051	0.054
1330	0.05	0.054	0.049	0.051	0.044	0.049	0.051	0.052	0.048	0.051

Table 2. Total atomic cross section of shape memory alloys.

Energy	Cast-Iron		NiTinol		Babit Metal		Stelite		Amalgam	
	Exp.	Theo.	Exp.	Theo.	Exp.	Theo.	Exp.	Theo.	Exp.	Theo.
122	36.451	36.769	48.611	49.6716	50.086	503.384	988.650	1000.97	1672.125	1678.595
356	15.599	16.0765	17.323	18.0302	64.692	67.2189	103.852	107.3726	169.154	174.699
511	12.893	13.5297	14.318	14.8484	43.970	45.9919	62.781	65.1276	99.828	104.45
662	11.938	12.4155	13.258	13.6111	37.905	40.4325	51.633	54.5664	84.115	86.8876
840	10.665	10.8238	11.667	11.8434	30.830	33.3567	41.658	43.4184	65.628	67.4765
1170	8.755	9.0729	9.545	3.8989	25.270	27.2919	32.857	34.0306	50.839	53.6115
1275	8.118	8.7545	9.015	9.3686	24.259	25.7757	30.510	31.6837	47.141	49.9142
1330	7.959	8.2876	8.662	9.01514	22.238	24.7648	29.924	30.5016	44.368	47.1411

Table 3. Total electronic cross section of shape memory alloys.

Energy	Cast-Iron		NiTinol		Babit Metal		Stelite		Amalgam	
	Exp.	**Theo.**	**Exp.**	**Theo.**	**Exp.**	**Theo.**	**Exp.**	**Theo.**	**Exp.**	**Theo.**
122	2.378	2.3984	1.944	1.9868	1.156	11.6174	6.093	26.1691	35.426	35.563
356	1.018	1.0487	0.693	0.7212	1.493	1.5513	2.715	2.8071	3.584	3.7012
511	0.841	0.8825	0.573	0.5939	1.015	1.0614	1.641	1.7026	2.115	2.2129
662	0.779	0.8098	0.530	0.5444	0.875	0.9331	1.350	1.4265	1.782	1.8408
840	0.696	0.706	0.467	0.4737	0.712	0.7668	1.089	1.1351	1.390	1.4295
1170	0.571	0.5918	0.382	0.3959	0.583	0.6298	0.859	0.8896	1.077	1.1358
1275	0.530	0.571	0.361	0.3747	0.560	0.5948	0.798	0.8283	0.999	1.0575
1330	0.519	0.5406	0.346	0.3606	0.513	0.5715	0.782	0.7974	0.940	0.9987