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Gamma ray attenuation parameters of inorganic nonlinear optical materials in the energy range 122 keV to 1330 keV

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In transmission experiments the mass attenuation coefficients of some inorganic nonlinear optical (NLO) materials viz; potassium dihydrogen phosphate (H_2KO_4P), ammonium dihydrogen phosphate ($NH_4H_2PO_4$) and sodium 1-decansulfonate ($C_{10}H_{21}SO_3Na$) have been determined at different photon energies 122 keV to 1330 keV and compared with the values obtained from the XCOM program. It has been observed that there is a good agreement between theoretical and experimental values. The total atomic cross section ($\sigma_{t,a}$), total electronic cross section ($\sigma_{t,el}$) and other related parameters have also been calculated from the obtained mass attenuation coefficient (μ_m) values and their variations with photon energy have been plotted. In the present work, it is observed that the variation of obtained values of μ_m, σ_t, σ_e, Z_{eff}, N_{eff}, ε, $\mu_{en/\rho}$ and $\sigma_{a,en}$ strongly depends on the photon energy. These parameters decrease or increase due to chemical composition and density of the sample. The values of μ_m of Sodium 1-decanesulfonate ($C_{10}H_{21}SO_3Na$) have been found greater than of potassium dihydrogen phosphate (H_2KO_4P) and ammonium dihydrogen phosphate ($NH_4H_2PO_4$) because the molecular weight of sodium 1-decanesulfonate is greater than other two samples in the entire energy region. The mass attenuation coefficient (μ_m) and other related parameters of all sample materials have been carried out and transmission curves have been plotted. The transmission curves shows the variation of all sample materials which decreases with increasing photon energy. The results of this present study can be useful in radiation dosimetry, radiation therapy and other technological applications.

Keywords: Mass attenuation coefficient, Total atomic cross sections, Total electronics cross sections, Molar exctinction coefficient

1 Introduction

The increasing use of photon interactions in various fields such as medical, industry, agriculture, nuclear weapon, and radiation shielding. The knowledge of absorption and scattering of gamma rays in the compound materials has become an interesting and exciting field of research[1]. The mass attenuation coefficient, total atomic cross-section, and total electronic cross sections are essential parameters for penetration and diffusion of x-ray or gamma ray in extended media. These parameters are valuable in many diverse fields such as radiation protection, nuclear diagnostics, nuclear medicine, and radiation dosimeter. The correct values of mass attenuation coefficients are widely used for solving different problems in radiation physics and radiation chemistry[2]. The accurate determination of the mass attenuation cross sections in different materials is therefore essential in the development of high accuracy semi-empirical formulation[3]. It is well known that mass attenuation coefficients mainly depend on the photon energy, the nature of the material and the density[4]. Numbers of research papers are available in various energy ranges on theoretical and experimental investigations to determine μ_m values in various elements and compounds/ mixtures[5-13]. Photon interactions absorption and scattering are related to the density and atomic number of an element. In case of compound materials it is related to effective atomic number and electron density. Therefore a single number cannot represent the atomic number uniquely across the entire energy range, as the partial interaction cross-sections have different elemental number dependence. This number is called the effective atomic number and varies with the energy[3]. Effective atomic numbers (Z_{eff}) play a key role in photon interactions for compound materials; it is very useful in different field like radiation shielding and radiation dosimetry. The effective atomic number is closely related to the effective electron density. Therefore the study of effective atomic numbers of compound material is very useful for various technological applications and also useful in radiation therapy and medical imaging[14]. The energy absorption

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in the entire medium can be calculated only when the value of Z_{eff} and N_{eff} are known. Thus, many researchers are focused on the determination of these parameters of compound materials in the energy region 5 keV to 1500 keV as the photons in this energy region are widely used in medical and biological applications in different method[15-19].

The gamma ray interaction studies on C, H, N and O based biological materials have been carried out by well collimated narrow beam good geometry set up and reported mass attenuation coefficient decreases with increasing photon energy[8,9,12,18-20]. Few investigations have been carried out the mass attenuations coefficient and other related parameters with high energy photons such as minerals, alloys and dosimetric materials[5-7,10-11]. Studies on attenuation and effective atomic number useful in radiation biology have also been reported[21-24]. Nonlinear optical materials have a key role in the study of the interaction of light with a substance under the situation which is the nonlinear response of the atoms[25] and these materials have numerous advantages due to their high density and high refractive index. Moreover, these materials properties are helpful for the progress of advanced optical telecommunication, laser, optics, photonics, optical switching, data storage, dosimetric and gamma-ray shielding materials. NLO materials are also used for the new development techniques of fabrication and growth of the crystal.

In literature; we observed that no experimental data is available on the study of some inorganic nonlinear optical materials. The main purpose of the present study is to measure the mass attenuation coefficient of some inorganic nonlinear optical materials and related parameters in the energy region 122 keV to 1330 keV by using the transmission method and compared with XCOM data.

2 Mathematical Calculations

2.1 Linear attenuation coefficient and mass attenuation coefficient

When a monochromatic beam of gamma ray is collimated on a sample, photons are attenuated by sample due to the absorption and scattering within interaction process. The transmitted beam of photons is represented by following equation:

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

where I_0 and I are the un-attenuated and attenuated photon intensities, μ_m (cm^2gm^{-1}) is mass attenuation coefficient of the materials 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 (4; 7; 14-16; 22-23):

$$\mu_m = \sum i W_i (\mu_m)_i \quad \ldots (2)$$

where W_i and $(\mu_m)_i$ are the weight fraction and mass attenuation coefficient of the i^{th} constituent element, respectively.

For a chemical compound the fraction by weight (W_i) is given by:

$$W_i = \frac{n_i A_i}{\sum_j n_i A_j} \quad \ldots (3)$$

where A_i is the atomic weight of i^{th} element and n_i is the number of formula units.

2.2 Total atomic cross section and total electronic cross section

The total molecular scattering cross section ($\sigma_{t,m}$) determined using mass attenuation coefficient (μ_m) is given by:

$$\sigma_{t,m} = \mu_m (M / N_A) \quad \ldots (4)$$

where $M = \sum_i n_i A_i$ is the atomic weight of the compound, N_A is the Avogadro's number (6.02486×10^{23} mol^{-1}), n_i is the total number of atoms in the molecule and A_i is the atomic weight of i^{th} element in a molecule.

The total atomic cross section ($\sigma_{t,a}$) has been determined from the following equation:

$$(\sigma_{t,a}) = \frac{1}{NA} \sum if_i A_i (\mu_m)_i \quad \ldots (5)$$

Similarly, the total electronic cross-sections ($\sigma_{t,el}$) have been determined from the following equation:

$$(\sigma_{t,el}) = \frac{1}{NA} \sum_i \frac{f_i A_i}{Z_i} (\mu_m)_i = \frac{\sigma_t}{Z_{eff}} \quad \ldots (6)$$

where $f_i = n_i / \sum_j n_j$ and Z_i are the fractional abundance and atomic number of constituent element i, respectively, n_i is the total number of atoms of the constituent element i and $\sum_j n_j$ is the total number of atoms present in the molecular formula.

2.3 Effective atomic number and effective electron density

Rearranging of the Eq. (6) yields the effective atomic numbers can be given as:

$$Z_{eff} = \frac{\sigma_{t,a}}{\sigma_{t,el}} \quad \ldots (7)$$

From Eq. (7), the effective atomic number (Z_{eff}) is closely related to the effective electron density (N_{eff}).

Now, the mass attenuation coefficient (μ_m) and electronic cross section ($\sigma_{t,el}$) made possible to calculate (N_{eff}) per unit volume of the samples is given by:

$$N_{eff} = \frac{N_A}{M} Z_{eff} \sum_i n_i = \frac{\mu_m}{\sigma_e} \quad \ldots (8)$$

where, μ_m and M/n is the mass attenuation coefficient and average atomic weight respectively, $\sum_i n_i = n$ shows total number of atoms.

2.4 Molar exctinction coefficient

The value of ε were determined using the following equation:

$$\varepsilon = 0.4343 \times N_A \times \sigma_t \quad \ldots (9)$$

2.5 Mass energy absorption coefficient and effective energy absorption cross section

The value of mass energy absorption coefficient (μ_{en}/ρ) were determined using the following equation:

$$\frac{\mu_{en}}{\rho} = \left(\sigma_{m,en} \times \frac{N_A}{M} \right) \quad \ldots (10)$$

Similarly, the effective atomic energy-absorption cross section ($\sigma_{a,en}$) can be calculated using the following equation:

$$\sigma_{a,en} = \frac{\sigma_{m,en}}{\sum_i n_i} \quad \ldots (11)$$

The symbols n_i and $\sum_i$ denote the number of atoms of the ith constituent element and the total number of atoms in the molecular formula, respectively.

3 Experimental Set-up and Measurements

Experiments were carried out on some inorganic nonlinear optical materials, i.e., potassium dihydrogen phosphate (H_2KO_4P), ammonium dihydrogen phosphate ($NH_4H_2PO_4$) and sodium 1-decansulfonate ($C_{10}H_{21}SO_3Na$). For measurement of incident and transmitted photon intensities a narrow beam good geometry set up was used. The schematic arrangement of the experimental setup is shown in Fig. 1. The samples were irradiated by gamma rays of energies 122, 360, 511,662, 840, 1170, 1275 and 1330 keV emitted by the six radioactive sources ^{57}Co, ^{133}Ba, ^{137}Cs, ^{54}Mn, ^{60}Co and ^{22}Na respectively were used in the present investigation. These isotopes are provided by BARC Mumbai and the detector used for the present experiment is NaI (Tl) (2″×2″) scintillation detector because of good resolution and energy selective and having good efficiency. The

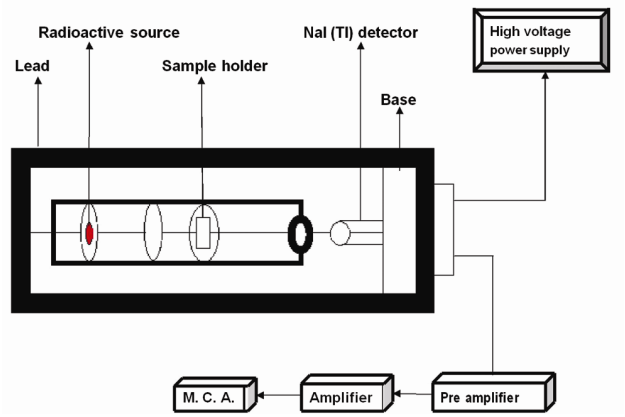

Fig. 1 — Schematic view of the experimental set up

signals from the detector were amplified and analyzed with 8K multichannel analyzer. For the preparation of sample in the form of pallet, the sample was weighed in a sensitive digital balance and having a good accuracy of measurements about 0.001 mg. The weighing samples were repeated three times to get the accuracy. The mean of this set of values was considered to be the mass of the sample. The KBr press machine was used to make the pallets of measured samples. The diameter of the pellets was measured by using the vernier caliper and mean value of the mass per unit area was determined in each case. The sample thickness was selected in order to satisfy the following ideal condition as far as possible Creagh[26]: $2 \leq \ln(I_0/I) \leq 4$.

While performing the experiments the temperature of the laboratory was kept constant and measured the values of unattenuated photon intensity I_0 that is without samples and attenuated photon intensity I that is with samples for three times and the mean values which are used for the calculation of the mass attenuation coefficients (μ_m) for all selected samples were calculated using Eq. (2). The values of mass attenuation coefficients were obtained using the XCOM program[27] over the large range of the photon energies and remaining parameter was calculated using the value of mass attenuation coefficients. All the inorganic nonlinear optical materials sample used in the present study were of high purity (99.9 %) so the sample impurity is negligible for the measured data and the error due to the non-uniform thickness of samples is also negligible. For the more accuracy the readings for all the samples were taken up to three decimal points to minimize the error and also care for the constant physical condition was taken.

4 Results and Discussion

In the present work, the values of mean atomic number, chemical formula and molecular weight of inorganic nonlinear optical materials are presented in Table 1. The experimental and theoretical results for the mass attenuation coefficients of potassium dihydrogen phosphate (H_2KO_4P), ammonium dihydrogen phosphate ($NH_4H_2PO_4$) and sodium 1-decansulfonate ($C_{10}H_{21}SO_3Na$) have been calculated at photon energy 122, 356, 511, 662, 840, 1170, 1275 and 1330 keV and tabulated in Table 2 and are plotted in Fig. 2. This is the most important physical quantity widely used for therapy computations and applicable in health physics, nuclear medicine and radiation shielding. It can be observed from the Fig. 2 and Table 2 that μ_m values depend on the photon energy and decrease with increasing photon energy; finally independent of photon energy due to dominance of Compton scattering and pair production in corresponding energy range. For current energy region, Compton scattering is dominating interaction process which occurred 10 keV to 1500 keV, and it has tremends application in diagnostic imaging.The measured σ_t and σ_e values for some inorganic nonlinear optical materials were presented in Table 3 and Table 4,

Table 1 — Mean atomic number (*Z*) calculated from chemical formula for inorganic nonlinear optical materials

Inorganic nonlinear optical material	Molar mass (g/mol)	Chemical formula	Mean atomic number <Z>
Potassium dihydrogen phosphate	136.09	(H_2KO_4P)	8.5
Ammonium dihydrogen phosphate	115.03	($NH_4H_2PO_4$)	5.0
Sodium 1-decanesulfonate	244.33	($C_{10}H_{21}SO_3Na$)	3.7

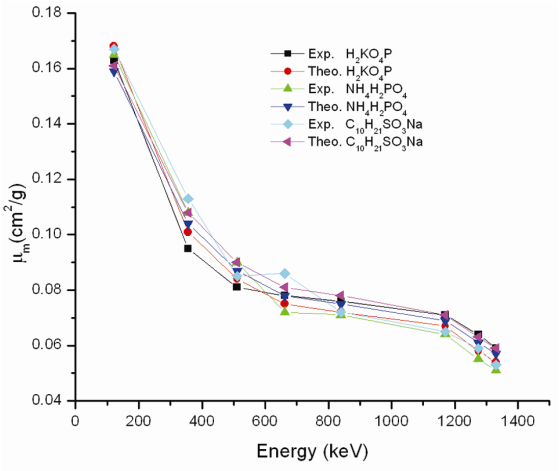

Fig. 2 — Typical plots of μ_m versus *E* for inorganic nonlinear optical materials

Table 2 — Mass attenuation coefficient (μ_m) of inorganic nonlinear optical materials from 122 keV to 1330 keV

Energy	H_2KO_4P		$NH_4H_2PO_4$		$C_{10}H_{21}SO_3Na$	
(keV)	Experimental	Theoretical	Experimental	Theoretical	Experimental	Theoretical
122	0.163	0.168	0.165	0.159	0.167	0.161
356	0.095	0.101	0.108	0.104	0.113	0.108
511	0.081	0.084	0.09	0.087	0.085	0.09
662	0.078	0.075	0.072	0.078	0.086	0.081
840	0.076	0.072	0.071	0.075	0.072	0.078
1170	0.071	0.067	0.064	0.069	0.065	0.071
1275	0.064	0.058	0.055	0.061	0.059	0.063
1330	0.059	0.054	0.051	0.057	0.053	0.059

Table 3 — Total atomic cross section ($\sigma_{t,a}$) of inorganic nonlinear optical materials from 122 keV to 1330 keV

Energy	H_2KO_4P		$NH_4H_2PO_4$		$C_{10}H_{21}SO_3Na$	
(keV)	Experimental	Theoretical	Experimental	Theoretical	Experimental	Theoretical
122	36.5797	37.7018	31.5012	30.3557	67.7240	65.2908
356	21.3195	22.6660	20.6190	19.8553	45.8252	43.7976
511	18.1777	18.8509	17.1825	16.6097	34.4703	36.4980
662	17.5044	16.8312	13.7460	14.8915	34.8758	32.8482
840	17.0556	16.1579	13.5551	14.3187	29.1984	31.6316
1170	15.9335	15.0358	12.2186	13.1732	26.3596	28.7928
1275	14.3626	13.0161	10.5004	11.6459	23.9264	25.5486
1330	13.2405	12.1184	9.7367	10.8822	21.4932	23.9264

Table 4 — Total electronic cross section ($\sigma_{t,el}$) of inorganic nonlinear optical materials from 122 keV to 1330 keV

Energy	H_2KO_4P		$NH_4H_2PO_4$		$C_{10}H_{21}SO_3Na$	
(keV)	Experimental	Theoretical	Experimental	Theoretical	Experimental	Theoretical
122	3.7112	3.8241	5.9720	5.7565	18.7903	18.1217
356	2.2603	2.4023	3.9699	3.8235	12.6859	12.1316
511	1.9560	2.0277	3.3249	3.2151	9.5369	10.1024
662	1.9032	1.8295	2.6696	2.8928	9.6414	9.0866
840	1.8716	1.7735	2.6411	2.7910	8.0699	8.7460
1170	1.7724	1.6730	2.3925	2.5800	7.2823	7.9562
1275	1.6030	1.4532	2.0541	2.2835	6.6079	7.0580
1330	1.4806	1.3554	1.9098	2.1351	5.9352	6.6095

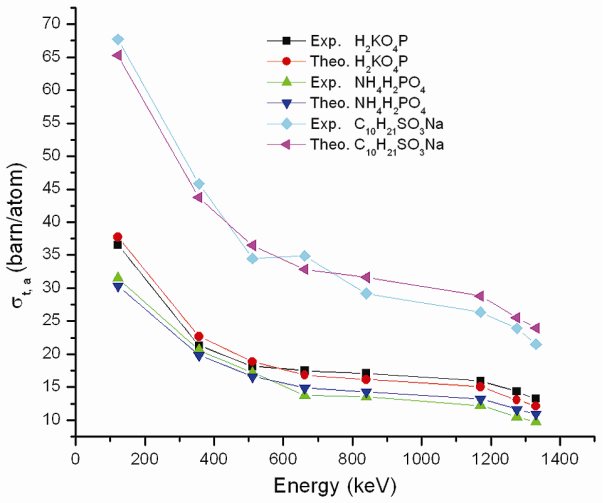

Fig. 3 — Typical plots of $\sigma_{t,a}$ versus E for inorganic nonlinear optical materials

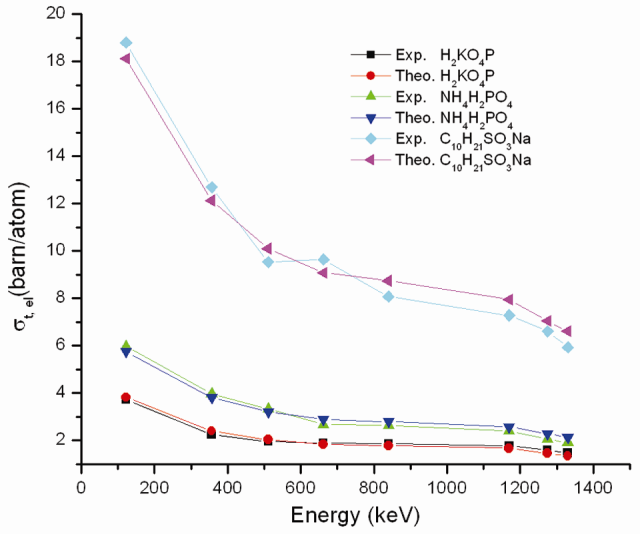

Fig. 4 — Typical plots of $\sigma_{t,el}$ versus E for inorganic nonlinear optical materials

respectively. The typical plot of $\sigma_{t,a}$ and $\sigma_{t,el}$ versus photon energy are plotted in Fig. 3 and Fig. 4, respectively. From Figs 3 and 4, it is clear that the value of sodium 1-decansulfonate ($C_{10}H_{21}SO_3Na$) sample is greater than other two sample, i.e., potassium dihydrogen phosphate (H_2KO_4P) and ammonium dihydrogen phosphate ($NH_4H_2PO_4$) because the molecular weight of sodium 1-decanesulfonate is greater than other two samples and the nature of $\sigma_{t,a}$ and $\sigma_{t,el}$ are nearly same to the photon energy. The total experimental value of u_m agree with total theoreotical values using XCOM data based on the mixture rule. The effective atomic numbers (Z_{eff}) as a function of energy is shown in Fig. 5. It can be clearly seen from Table 5 that the nature of Z_{eff} is similar for all samples and the measured variation of Z_{eff} is vary with photon energy and tends to a constant value. The known values of effective atomic number (Z_{eff}) can be utilized to calculate absorbed dose and buildup factor for dose

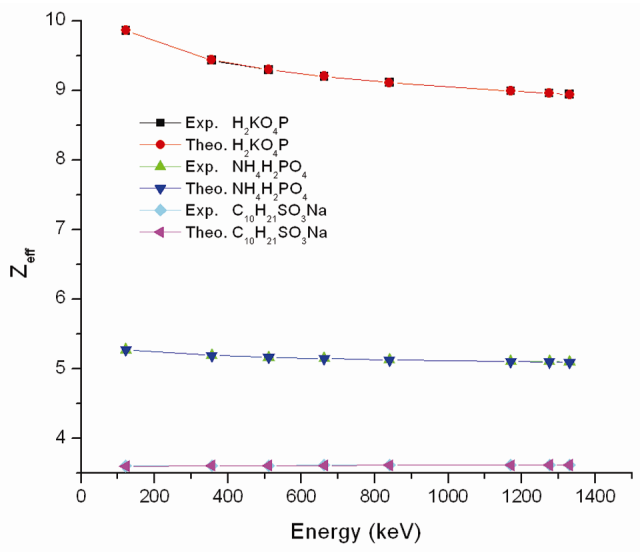

Fig. 5 — Typical plots of Z_{eff} versus E for inorganic nonlinear optical materials

Table 5 — Effective atomic numbers (Z_{eff}) of inorganic nonlinear optical materials from 122 keV to 1330 keV

Energy	H_2KO_4P		$NH_4H_2PO_4$		$C_{10}H_{21}SO_3Na$	
(keV)	Experimental	Theoretical	Experimental	Theoretical	Experimental	Theoretical
122	9.8565	9.8590	5.2748	5.2733	3.6042	3.6029
356	9.4322	9.4350	5.1938	5.1929	3.6123	3.6102
511	9.2932	9.2965	5.1678	5.1662	3.6144	3.6128
662	9.1975	9.2000	5.1491	5.1478	3.6173	3.6150
840	9.1127	9.1109	5.1324	5.1304	3.6182	3.6167
1170	8.9898	8.9875	5.1071	5.1059	3.6197	3.6189
1275	8.9597	8.9570	5.1119	5.1001	3.6209	3.6198
1330	8.9428	8.9411	5.0982	5.0968	3.6213	3.6200

Table 6 — Effective electron densities (N_{eff}) of inorganic nonlinear optical materials from 122 keV to 1330 keV

Energy	H_2KO_4P		$NH_4H_2PO_4$		$C_{10}H_{21}SO_3Na$	
(keV)	Experimental	Theoretical	Experimental	Theoretical	Experimental	Theoretical
122	3.5137	3.5146	3.3155	3.3145	3.1996	3.1984
356	3.3624	3.3634	3.2646	3.2640	3.2068	3.2049
511	3.3129	3.3140	3.2482	3.2472	3.2086	3.2072
662	3.2787	3.2796	3.2365	3.2357	3.2112	3.2092
840	3.2485	3.2479	3.2260	3.2247	3.2120	3.2107
1170	3.2047	3.2039	3.2101	3.2093	3.2133	3.2126
1275	3.1940	3.1930	3.2131	3.2057	3.2144	3.2134
1330	3.1879	3.1873	3.2045	3.2036	3.2147	3.2136

Table 7 — Molar extinction coefficients (ε) of inorganic nonlinear optical materials from 122 keV to 1330 keV

Energy	H_2KO_4P		$NH_4H_2PO_4$		$C_{10}H_{21}SO_3Na$	
(keV)	Experimental	Theoretical	Experimental	Theoretical	Experimental	Theoretical
122	95.7144	98.6504	82.4259	79.4286	177.2064	170.8397
356	55.7845	59.3077	53.9515	51.9533	119.9061	114.6005
511	47.5636	49.3252	44.9596	43.4609	90.1949	95.5004
662	45.8020	44.0404	35.9677	38.9650	91.2560	85.9504
840	44.6276	42.2788	35.4681	37.4663	76.4004	82.7671
1170	41.6915	39.3427	31.9713	34.4690	68.9725	75.3392
1275	37.5811	34.0579	27.4753	30.4726	62.6058	66.8503
1330	34.6451	31.7091	25.4771	28.4744	56.2392	62.6058

and radiation therapy calculation. The mass attenuation coefficient (μ_m) and total electronic cross section ($\sigma_{t,el}$) values were used to calculate (N_{eff}) same are tabulated in Table 6. The measured values of effective electron densities (N_{eff}) are varying very small with energy as shown in Fig. 6, it is observed that the values of effective electron densities (N_{eff}) are nearly similar between energy ranges 1150 keV to 1170 keV. The variation of effective atomic number was systematically studied with respect to effective atomic weight and the above relation has been satisfied. The value of total atomic cross section can be used to calculate the value of molar extinction coefficient tabulated in Table 7 and displayed in Fig. 7. It is clear from Table 7 and Fig. 7

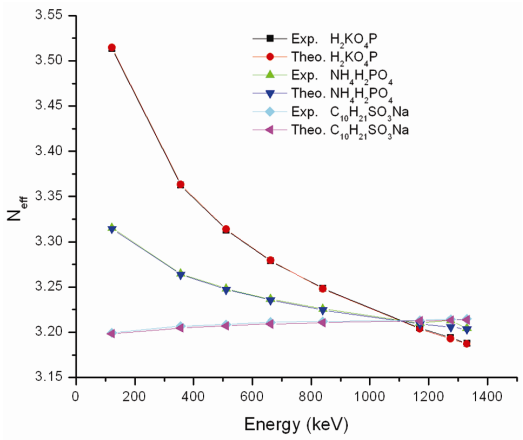

Fig. 6 — Typical plots of N_{eff} versus E for inorganic nonlinear optical materials

that the change in experimental values of ε for the present sample initially decrease and tend to be almost constant as a function of gamma-ray energy is due to the impurities and oxidation in the samples. In the compound materials, like the inorganic nonlinear optical materials studied in the present case, mass energy absorption coefficient and effective atomic energy absorption cross section for present samples were determined using (μ_{en}/ρ) and ($\sigma_{a,en}$) values which same are given in Table 8 and Table 9 and displayed in Fig. 8 and Fig. 9, respectively. From Figs 8 and 9, it can be seen that the typical variation of mass energy absorption coefficient and effective atomic energy absorption cross section versus photon energy for all sample materials. It is clearly seen from all the observed and calculated data of

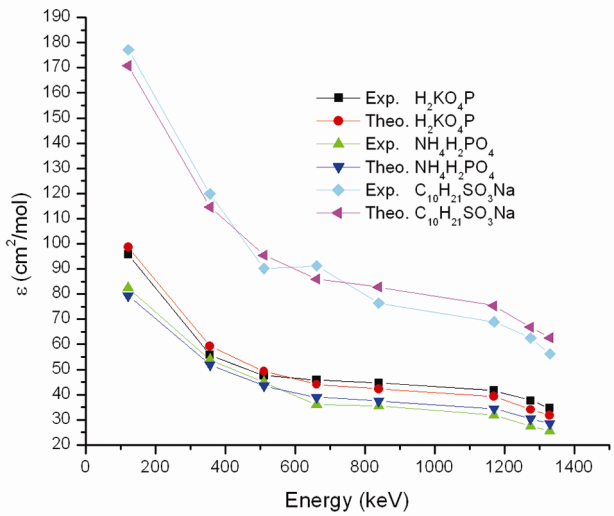

Fig. 7 — Typical plots of Ɛ versus *E* for inorganic nonlinear optical materials

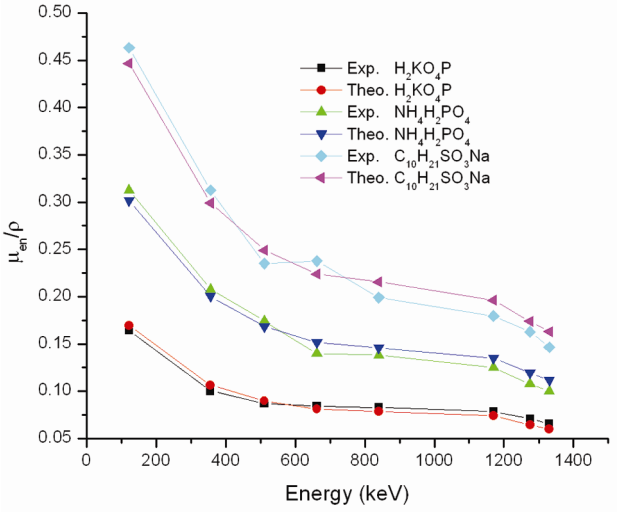

Fig. 8 — Typical plots of μ_{en}/ρ versus *E* for inorganic nonlinear optical materials

Table 8 — Mass energy absorption coefficient (μ_{en}/ρ) of inorganic nonlinear optical materials from 122 keV to 1330 keV

Energy	H_2KO_4P		$NH_4H_2PO_4$		$C_{10}H_{21}SO_3Na$	
(keV)	Experimental	Theoretical	Experimental	Theoretical	Experimental	Theoretical
122	0.1643	0.1693	0.3128	0.3015	0.4633	0.4469
356	0.1001	0.1064	0.2079	0.2003	0.3128	0.2991
511	0.0866	0.0898	0.1741	0.1684	0.2352	0.2491
662	0.0843	0.0810	0.1398	0.1515	0.2377	0.2241
840	0.0829	0.0785	0.1383	0.1462	0.1990	0.2157
1170	0.0785	0.0741	0.1253	0.1351	0.1796	0.1962
1275	0.0710	0.0643	0.1076	0.1196	0.1629	0.1740
1330	0.0655	0.0600	0.1000	0.1118	0.1464	0.1630

Table 9 — Effective atomic energy absorption cross sections ($\sigma_{a,en}$) of inorganic nonlinear optical materials from 122 keV to 1330 keV

Energy	H_2KO_4P		$NH_4H_2PO_4$		$C_{10}H_{21}SO_3Na$	
(keV)	Experimental	Theoretical	Experimental	Theoretical	Experimental	Theoretical
122	0.4639	0.4780	0.4977	0.4797	0.5220	0.5034
356	0.2825	0.3003	0.3308	0.3186	0.3524	0.3370
511	0.2445	0.2535	0.2771	0.2679	0.2649	0.2806
662	0.2379	0.2287	0.2225	0.2411	0.2678	0.2524
840	0.2340	0.2217	0.2201	0.2326	0.2242	0.2429
1170	0.2215	0.2091	0.1994	0.2150	0.2023	0.2210
1275	0.2004	0.1816	0.1712	0.1903	0.1836	0.1961
1330	0.1851	0.1694	0.1592	0.1779	0.1649	0.1836

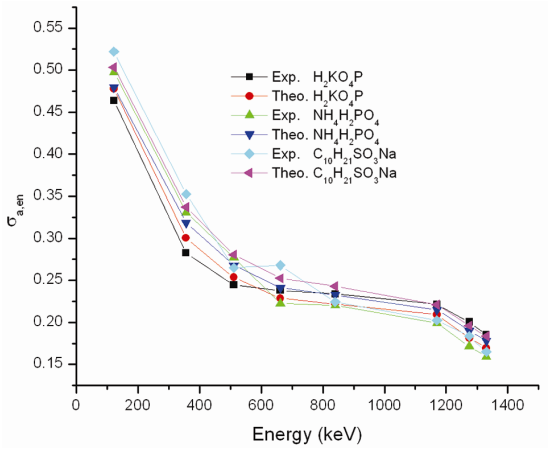

Fig. 9 — Typical plots of $\sigma_{a,en}$ versus *E* for inorganic nonlinear optical materials

all sample shows different variation in entire energy region and at the energy 662 keV sodium 1-decansulfonate ($C_{10}H_{21}SO_3Na$) shows increasing value of μ_m, $\sigma_{t,a}$, $\sigma_{t,el}$, ε, $\mu_{en/\rho}$ and $\sigma_{a,en}$ because of impurity added while making palates.

5 Conclusions

In the experimental study, the mass attenuation coefficient of some inorganic nonlinear optical materials such as potassium dihydrogen phosphate (H_2KO_4P) and ammonium dihydrogen phosphate ($NH_4H_2PO_4$) and sodium 1-decansulfonate ($C_{10}H_{21}SO_3Na$) has been calculated at various photon energies 122, 356, 511, 662, 840, 1170, 1275 and 1330 keV, respectively. The present investigation has been undertaken to get information about (μ_m) values and other related parameters, i.e., ($\sigma_{t,a}$) and ($\sigma_{t,el}$) for some inorganic nonlinear optical materials. It has been observed that the present data on μ_m values are useful for radiation dosimetry, radiation therapy and other technological applications.Total atomic cross section ($\sigma_{t,a}$) and total electronic cross section ($\sigma_{t,el}$) decrease initially with photon energy similar to μ_m then independent of the energy due to Compton scattering and pair production dominate in the respective energy region. In this paper first time we reported the experimental data on (μ_m), ($\sigma_{t,a}$), ($\sigma_{t,el}$) (Z_{eff}), (N_{eff}), (ε), (μ_{en}/ρ), and ($\sigma_{a,en}$) of some inorganic nonlinear optical materials at different photon energy regions.

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References

1 Manohara S R & Hanagodimath S M, *Nucl Instrum Meth Phys Res B*, 258 (2007) 321.
2 Kaewkhao J, Laopaiboon J & Chewpraditkul W, *J Quant Spectrosc Radiat Transfer*, 109 (2008) 1260.
3 Jackson D F & Hawkes D J, *Phys Rep*, 70 (1981) 169.
4 Baltas H, Celik S, Cevik U & Yamaz E, *Radiat Meas*, 42 (2007) 55.
5 Kiran K T & Venkata R K, *Radiat Phys Chem*, 50(6) (1997) 545.
6 El-Kateb A H, Rizk R A M & Abdul-Kadar A M, *Ann Nucl Energy*, 27(14) (2000) 1333.
7 Murthy V R K, *Radiat Phys Chem*, 71 (2004) 667.
8 Gowda S, Krishnaveni S & Gowda R, *Nucl Instrum Meth Phys Res B*, 239(4) (2005) 361.
9 Manohara S R, Hanagodinath S M & Gerward L, *Phys Med Biol*, 53(20) (2008) N377.
10 Han I, Demir L & Sahin M, *Radiat Phys Chem*, 78(9) (2009)760.
11 Han I & Demir L, *Radiat Meas*, 44 (2009) 289.
12 Pawar P P & Bichile G K, *Radiat Phys Chem*, 92 (2013) 22.
13 Gaikwad D K, Pawar P P & Selvam T P, *Pramana*: *J Phy*, 87 (2016) 12.
14 Hine G J, *Phys Rev*, 85 (1952) 725.
15 Kurudirek M & Onaran T, *Radiat Phys Chem*, 112 (2015) 125.
16 Demir D, Tursucu A & Oznuluer T, *Radiat Envirom Biophys*, 51 (2012) 469.
17 Salehi D, Sardari D & Jozani M S, *J Radiat Res Appl Sci*, 8 (2015) 439.
18 Kore P S & Pawar P P, *Radiat Phys Chem*, 98 (2014) 86.
19 Ladhaf B M & Pawar P P, *Radiat Phys Chem*, 109 (2015) 89.
20 Kore P S, Pawar P P & Selvam T P, *Radiat Phys Chem*, 119 (2016) 74.
21 Marashdeh M W, Al-Hamarneh I F, Eid M Abdel, Munem A A, Tajuddin A A & Saleh Al-Omari, *Results in Phys*, 5 (2015) 228.
22 Rao A S M, *Int J Adv Sci Technol*, 81 (2015) 25.
23 Kucuk N, Cakir M & Isitman N A, *Radiat Protect Dosim*, 153 (2013) 127.
24 Akman F, Durak R, Turhan M F & Kacal M R, *Appl Radiat Isot*, 101 (2015) 107.
25 Suresh S, Ramanand A, Jayaraman D & Mani P, *Rev Adv Mater Sci*, 30 (2012) 175.
26 Creagh D C, *Nucl Instrum Meth A*, 255 (1987) 1.
27 Gerward L, Guilbert N, Jensen K B & Levring H, *Radiat Phys Chem*, 71 (2004) 653.