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The Experimental Measurements of Total Mass Attenuation Coefficients in Arsenic Oxide

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Abstract

Measurements of K-shell mass attenuation coefficients are reported for the first time in Arsenic oxide (As_2O_3). Experiments are performed using Arsenic Oxide extended range HPGe detector. To achieve measurements at many small and regular energy intervals, secondary X-ray emission technique using "Seventeen Scatters" is employed. The results are in agreement with the proposed theoretical estimates. No evidence could, however be gained in favor of microscopic theories such as RRS and EXAFS, insofar as there are no energy points within a range of 100eV on either side of the K-edge.

Keywords

Mass Attenuation, Arsenic Oxide, K-Shell, Energy Intervals

1. Introduction

There are some but not specific measurements tabulated on the energy range dependence of k-shell mass attenuation—sections in the element, with which this research has identified. Along with the common notion that Arsenic is a highly poisonous substance, it needs to be understood that this element pertains to the low energy region of 5 KeV to 17 KeV and covers K-edge of arsenic which is pegged at 11.867 KeV. This data is important not only because it provides much needed experimental values but also assimilates the phenomena of anomalous X-ray scattering near the k-edge of the element. To do such an investigation, it is of primary importance to have experimental data close to the K-edge in regular intervals with a short magnitude. This research asserts that this is not possible even by applying radioactive sources as is normally done. This research therefore argues that characteristic X-rays produced by secondary excitation in suitable neighboring elements, namely Cr, Mn, Fe, Co,

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Ni, Cu, Zn, Ge, Se, Br, Sr and Y, have all been used for the measurement of total mass attenuation coefficients.

2. Experimentation

The experimental arrangement is illustrated in **Figure 1**. The primary source R, which is a strong Pu^{238} point source of 10 mci, is properly shielded to allow controlled X-rays to interface on the selected scatter, S. The characteristic X-rays from the scatters route through a Compton shield circular slit and then through the absorber film of Arsenic oxide and two more circular slits (filters) to reach the detector stationed in a lead box, this box shields the detector from unwanted radiation emitted if any from other origin(S).

The detector used is an extended range HpGe detector with a low energy cut-off at 3 KeV and has an energy range of Max 1000 KeV and with 5 Mil Beryllium windows. The energy resolution of the detector is locked at 200 eV and at 5.9 KeV.

2.1. Axioms Description

Referencing the absorber foil preparation, the required thickness for the As_2O_3 compound was deposited on a Watt Man no. 1 filter paper discs in the prefixed energy range namely 5 to 18 KeV. The compound thickness under investigation for transmission between one per cent and ten per cent is estimated using an analysis of the total cross-section's from the tabulations of Scofield tables. The thickness of the applied absorbers ranges from 3 mg/cm^2 to 200 mg/cm^2 to facilitate compound preparation within the walls of the absorber.

2.2. Protocols Description

For absorber preparation, filter paper technique as described by Sharanabasappa *et al.* (2010) [1] is applied. These experimental absorbers are prepared by creating a circular hallow of 1cm diameter in three cello phone rings attached one over the other on a cello-phone sheet and covered on the dorsal side also with the same cello-phone sheet after depositing the As_2O_3 compound uniformly, inside the created hallow. The absorber so prepared is held firmly stretched amidst two thin "Mylar Rings" to be positioned vertically within the experimental arrangement.

The Uniformity of compound deposition is again tested using the X-Ray transmission methodology. Arsenic Oxide absorber was found to be undisturbed as it was uniformly distributed throughout the experiment because of Arsenic's dynamic and inherent characteristics associated to its surface tension and its thickness. The mass attenuation coefficient is obtained from the formula.

$$\mu/r = L_n\{I_o/I\}$$

where I_o is the intensity, L_n is the transmission intensity, ρ is the density of mass and x is the thickness obtained from the mass "m" and area "a" of the liquid film as

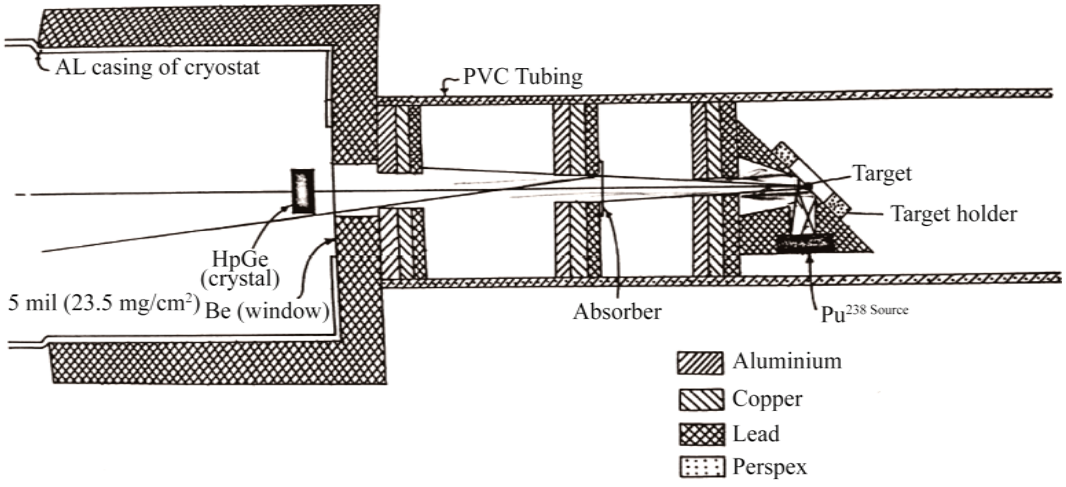

Figure 1. Geometrical set-up showing Detector, Absorber, Exciter and Primary sources with graded stilts.

$$x\rho = m/a.$$

The experimental mass attenuation coefficients of Arsenic Oxide are measured at eighteen energy points in the low energy region of 5 to 17 KeV. The elemental mass attenuation coefficients are deduced based on Sum-Rule and are compared with previous research works with a limitation of data availability.

Reemphasizing that Arsenic is a highly poisonous substance and that there are no earlier measurements of total photon attenuation coefficients in this element at any photon energy, it needs to be mentioned that special care had to be exercised in preparing the targets and iterating the target etc., because of its highly poisonous nature to human beings. The present composition of the compound Arsenic Oxide (As_2O_3) is a weighted contribution of Arsenic at 75 per cent and Oxygen at 25 per cent by weight to the molecular weight of the total compound. As said, "Sum-rule" is applied to derive the experimental mass-attenuation coefficient of Arsenic from those of the compound and one presented in **Table 1** at eighteen energy points in the range of 5 KeV to 17 KeV. It needs to be observed from **Table 1** that out of these eighteen energies, eleven energies remain below the K-edge, while the remaining seven energies lie above the K-edge (The K-edge energy being 11.867 KeV). The mass attenuation coefficients of element Arsenic are determined assuming the Sum-Rule to be valid even in this energy region also.

3. Data Analysis and Interpretation

Column 3 in **Table 1** provides the theoretical estimates of mass attenuation coefficients derived from the total photon attenuation cross-section obtained by combining the photo electric cross-sections of Scofield [2] coherent and incoherent scattering cross-sections of Hubbel [3] and Hubbell & Overbo [4] respectively.

Table 1. Measured total photon mass-attenuation coefficient element arsenic compared with theoretical and semi-empirical values.

		Theoretical values of Scofield + Hubble + Hubble & Overbo		Victoreen *et al.*	
Energy (KeV)	Experimental values	Values	Deviation (%)	Values	Deviation (%)
5.411	222.17 ± 3.99	218.89	1.5	231.61	4.00
5.895	175.72 ± 3.17	173.64	1.2	181.73	3.20
6.404	140.40 ± 2.54	138.74	1.2	143.50	2.00
6.925	113.64 ± 2.05	112.19	1.3	115.31	1.40
7.472	92.49 ± 2.78	91.22	1.4	92.35	0.15
8.041	76.19 ± 1.38	75.22	1.3	74.73	1.90
8.631	62.28 ± 1.13	61.55	1.2	60.92	2.20
9.572	45.76 ± 0.83	46.41	1.4	45.15	1.30
9.876	43.20 ± 0.82	42.65	1.3	41.30	4.90
10.986	32.33 ± 0.59	31.86	1.5	30.26	6.80
11.210	30.64 ± 0.58	30.10	1.8	28.54	7.30
11.907	191.42 ± 3.34	177.57	7.8	174.26	9.80
12.502	158.71 ± 2.86	156.83	1.2	154.91	2.40
13.299	135.59 ± 2.46	133.85	1.3	133.13	1.80
14.142	112.48 ± 2.03	114.20	1.5	114.12	1.40
140933	100.63 ± 1.82	99.14	1.4	99.30	1.30
15.859	85.28 ± 1.54	84.19	1.2	85.11	0.20
16.766	74.17 ± 1.35	73.15	1.4	73.63	0.76

It may be seen from **Table 1**, that the errors associated with the present experimental attenuation coefficients are less than 2.00 per cent. These errors include statistical error of 0.5 per cent at the maximum and 1.00 per cent due to other effects such as the dead time correction, error in estimation of mass of the absorber and error due to a possible impurity of the element. This research is one of the first pioneering works to feature a distribution of K-edge values above and below the KeV. Of the eighteen energies, eleven energies fall below the K-edge, while the remaining seven energies are above the K-edge, the K-edge energy being pegged at 11.867 KeV. The mass attenuation coefficients of the element Arsenic are determined assuming the "Sum-Rule" to be valid in this energy region. This is the positive proof for the validity of "Sum-rule" even in this low energy region. It may also, be noticed from **Table 1**, that as the values move closer to the K-edge on either side the deviations from theory are quite large compared to the experimental error. The above assertion is a point to focus attention, on the basis of the prediction due to R.R.S., EXAFS and XANES. There are two energy points above the K-edge within the range of 1 KeV, one being very close at just 40 eV, while the other being located at 635 eV. Notably, the measured value at the first point at 40 eV from the edge deviates by a large span of 7.8 per cent the second point which is a bit further away at 635 eV from the edge and is in satisfactory agreement with the theoretical value with a negligible percentage deviation of 1.2 per cent.

This feature suggests that the large deviation of the first data point renders support to the theoretical predictions due to EXAFS and/or XANES, in that their range of manifestation from the K-edge is rather short and will die away even at a distance 635 eV from the K-edge, hence proving that these are highly localized effects and may manifest very close to the K-edge within an energy range of a few 100 eV. There are two energy points within 1 KeV below the K-edge, namely 10.986 KeV and 11.21 KeV which are respectively at 881 eV and 635 eV below the K-edge.

From **Table 1** and **Table 2** the total mass attenuation coefficients at these two points are quite in agreement with theory. Referring to the fact that there are no RRS effects at these points, it may be in lieu of the fact that

Table 2. Measured total photon mass-attenuation coefficient element arsenic compared with theoretical and semi-empirical values.

		Power law		Orlic *et al.*		L. Gerward *et al.*	
Energy (KeV)	Experimental values	Values	Deviation (%)	Values	Deviation (%)	Values	Deviation (%)
5.411	222.17 ± 3.99	218.92	1.5	219.20	1.30	226.48	1.90
5.895	175.72 ± 3.17	173.85	1.0	173.92	1.10	179.43	2.10
6.404	140.40 ± 2.54	139.13	0.9	138.94	1.10	143.13	1.90
6.925	113.64 ± 2.05	112.96	0.6	112.50	1.00	115.77	1.80
7.472	92.49 ± 2.78	91.97	0.5	91.35	1.24	93.83	1.40
8.041	76.19 ± 1.38	75.47	0.9	74.74	1.90	76.61	0.50
8.631	62.28 ± 1.13	62.40	0.2	61.59	1.10	62.99	1.10
9.572	45.76 ± 0.83	47.27	3.0	46.43	1.40	47.29	3.20
9.876	43.20 ± 0.82	4352	0.7	42.67	1.20	43.52	0.70
10.986	32.33 ± 0.59	32.70	1.1	31.89	1.40	30.15	3.70
11.210	30.64 ± 0.58	30.93	0.3	30.13	2.90	29.43	5.40
11.907	191.42 ± 3.34	180.55	6.7	177.64	7.80	184.00	4.03
12.502	158.71 ± 2.86	158.22	0.3	157.01	1.10	161.93	2.00
13.299	135.59 ± 2.46	133.84	1.3	134.12	1.10	137.63	1.40
14.142	112.48 ± 2.03	113.33	1.2	114.15	1.40	117.01	3.80
140933	100.63 ± 1.82	97.81	2.8	99.46	1.20	101.28	0.64
15.859	85.28 ± 1.54	63.11	2.6	84.99	0.30	86.29	1.20
16.766	74.17 ± 1.35	71.50	3.7	73.41	1.03	74.37	0.20

they are quite far from the K-edge exceeding even the 500 eV mark away from the K-edge. This fact again summarily asserts that the effects due to RRS will not be felt a few hundreds of eV away from the K-edge. Column 4 through 7 of **Table 2**, furnishes the semi-empirical predictions of different authors and describes along with the percentage deviation with the present experimental values.

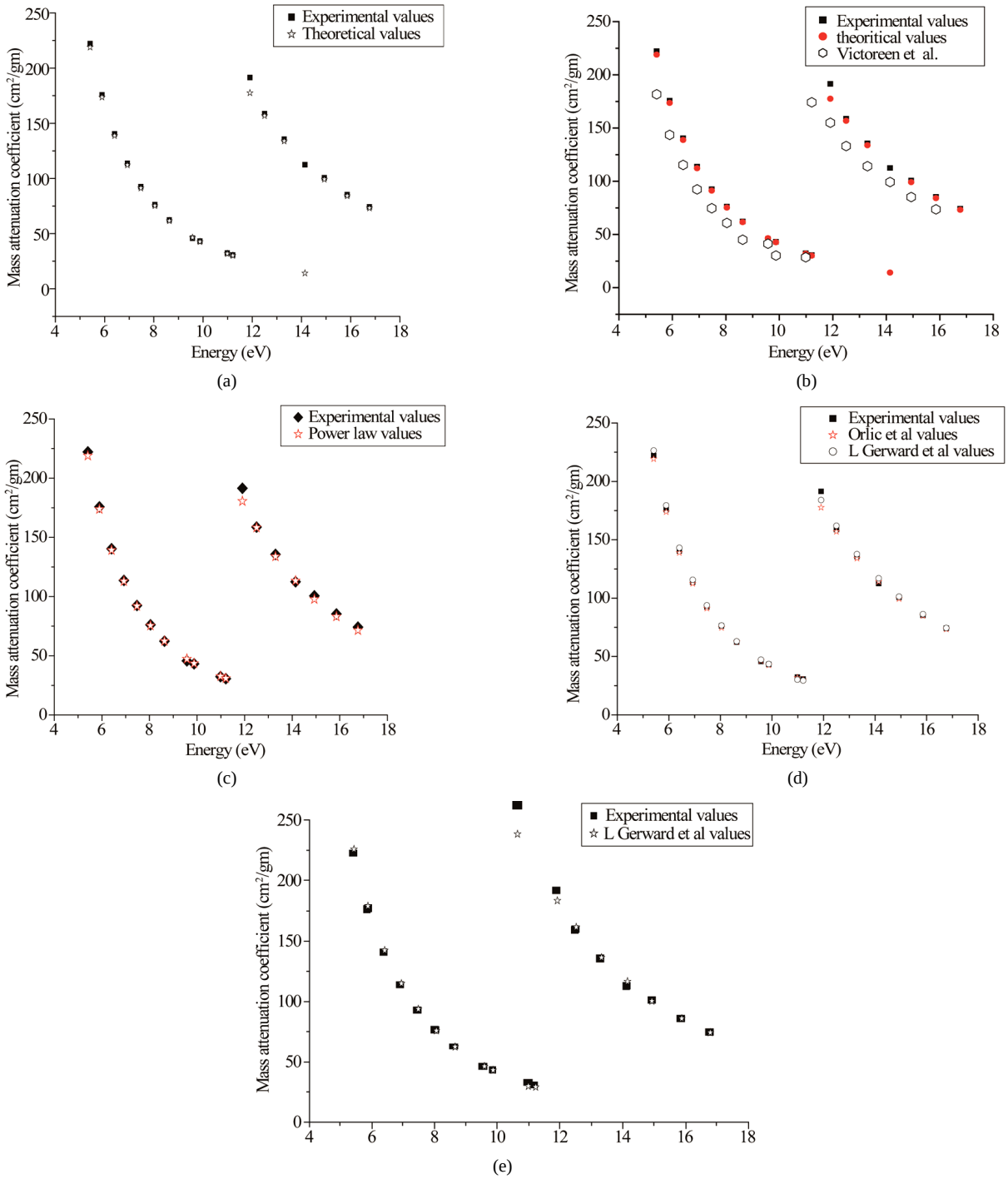

Figure 2. (a) Comparison of theoretical and experimental mass attenuation coefficient of arsenic; (b) Theoretical and experimental mass attenuation coefficient of arsenic with Victoreen's values; (c) Comparison of experimental mass attenuation coefficient of arsenic with power law; (d) Comparison of experimental mass attenuation coefficient of arsenic with Orlic's values; (e) Comparison of experimental mass attenuation coefficient of arsenic with L. Gerward's values.

A critical examination of these semi-empirical values reflects that in Arsenic the values due to Ortic *et al*. are quite close to the experimental values, where as the values due to Gerward whose power law is supposed to be more refined taking into consideration the functional dependence on Z and E and the exponents are quite out of tune with the present experimental values with large percentage deviations. The values due to Victoreen, *et al.* are coinciding with the normal and deviate from the experimental values quite significantly. The values attributed to Power Law seem to fit the experimental values closely except at the edge and the three highest points in the chosen energy range. The semi-empirical scheme due to Orlic *et al.* [5], stands best in fitting the present experimental values while those due to the Simple Power Law seem to be the next best.

The predictions of the semi-empirical schemes are also given in graphical format in **Figure 2(a)** to **Figure 2(e)** each graph plotting the values due to one-semi-empirical scheme along with the experimental and theoretical values for close comparison. **Figure 2(a)** shows experimental values compared with the theoretical values alone. The values due to Victoreen are plotted in **Figure 2(b)**. The values due to Power Law in **Figure 2(c)** those due to Orlic *et al.* [5] are plotted in **Figure 2(d)** those values due to the improved Power Law of Gerward are plotted in **Figure 2(e)**.

4. Conclusions

There are no earlier experimental measurements on the mass attenuation coefficients in this element within the energy range or even outside a given range. The present investigations reveal that the predictions of the edge effects due to RRS, EXAFS and XANES are more significant in higher Z group elements.

The results of this research show and re-emphasize the primary importance of having experimental data close to the K-edge in regular intervals with a short magnitude and assert that characteristic X-rays produced by secondary excitation in suitable neighboring elements, namely Cr, Mn, Fe, Co, Ni, Cu, Zn, Ge, Se, Br, Sr and Y can be used for the measurement of total mass attenuation coefficients.

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