Studies on the Incoherent scattering of some Steel alloys for Compton Effect in the incident angular range 60^0-100^0

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Abstract: *In this paper we report the differential incoherent scattering cross sections and effective atomic number of some Steel alloys at three incident gamma ray energies 279.1keV, 661.6keV and 1115.5keV at three scattering angles of 60^0, 80^0 and 100^0. It was found that all the steel samples used are characterized by a mean effective atomic number of 25.85 for Compton Effect. The results obtained are first of their kind at these energies and are expected to be important because the energies and the Steel alloy samples chosen have a variety of applications in Radiation Physics and Chemistry, Condensed matter Physics, Compton scattering imaging etc.*

Keywords*: Differential incoherent scattering cross sections, Effective atomic numbers, Compton Effect*

Introduction:

Increasing use of radioactive isotopes in many fields of science and technology demands a detailed knowledge of the processes involved in the interaction of gamma rays with matter. In particular, it can be observed that the photons of energy above 200keV up to 1500keV are widely used in several applications such as industrial radiography, archeometry, chemotherapy, medical diagnostics, Compton scatter imaging etc., [1].

Hine [2] pointed out that in the studies on photon interactions with complex media, the atomic number of the complex media for photon interaction cannot be usually represented uniquely by a single number across the entire energy region, similar to the case of elements. This number of the complex media for photon interaction is called the effective atomic number and is found to vary with energy. The effective atomic number signifies as to how a composite material would interact with incident photons at a given energy in a way similar to a single element of atomic number equivalent to that composite material. Since Steel alloys are also being widely used for shielding and other needs of human enterprise in several applications of radiation in the energy region 200keV to 1500keV, the most dominant mode of interaction of gamma rays with matter is the incoherent scattering by atomic electrons. Hence, knowledge of the differential incoherent scattering cross sections and Effective atomic number of Steel alloys in this energy region will be quite useful.

A survey on the incoherent scattering cross section measurements reveals the fact that although measurements of the cross sections of pure elements abound in literature [3], the reports on the measurement of the differential incoherent scattering cross sections of alloys and their effective atomic numbers Z_{eff} are relatively scarce. Hence we felt it felt worthwhile to measure the differential incoherent scattering cross sections of some steel alloys as in Table 1. (we named the samples as Steel 1, Steel 2, Steel 3, Steel 4 for our reference, the percentage compositions are mentioned as supplier) along with their Effective atomic numbers. The differential incoherent cross sections and effective atomic numbers were measured at three incident gamma ray energies 279.1keV, 661.6keV and 1115.5keV and three scattering angles of 60^0, 80^0 and 100^0. The effective atomic number of these steel alloys for Compton Effect also has been determined by using a method described in our earlier paper [4]. Possible conclusions are obtained based on the present study.

Table1 : Compositions of the some Steel alloys in percentage as specified by the supplier.

Sample	Composition in Percentage
Steel 1	Fe = 97.0371, C = 0.42, Si = 0.25, Mn = 0.89, P = 0.021, S = 0.11, Cr = 1.05, Mo = 0.2, Ni = 0.06, Al = 0.049, Cu = 0.01, Ti = 0.0019
Steel 2	Fe = 98.4206, C = 0.39, Si = 0.26, Mn = 0.79, P = 0.014, S = 0.008, Cr = 0.04, Mo = 0.01, Ni = 0.02, Al = 0.036, Cu = 0.01, Ti = 0.0014
Steel 3	Fe = 96.79604, C = 1.03, Si = 0.31, Mn = 0.32, P = 0.015, S = 0.012, Cr = 1.43, Mo = 0.01, Ni = 0.03, Al = 0.034, Cu = 0.01, Ti = 0.0026
Steel 4	Fe = 98.5777, C = 0.033, Si = 0.26, Mn = 0.66, P = 0.020, S = 0.021, Cr = 0.89, Mo = 0.16, Ni = 0.03, Al = 0.040, Cu = 0.01, Ti = 0.0013

Experimental procedure:

The differential incoherent scattering cross sections of some steel alloys are measured at three scattering angles of 60^0, 80^0 and 100^0 on a goniometry assembly for 661.6keV energy gamma rays emitted by ^{137}Cs source which was procured in the form of a radiographic capsule from M/S Amersham, U.K. A schematic diagram of the experimental set up is as shown in Figure.1

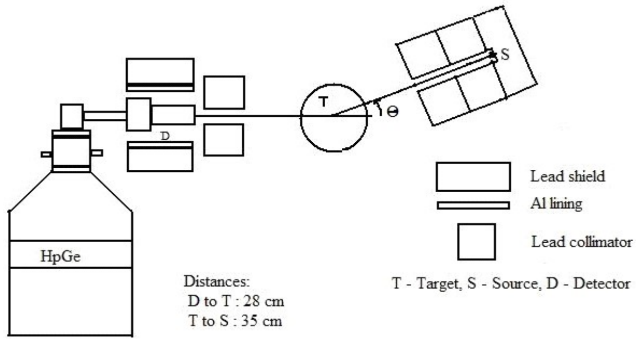

Figure 1. Schematic diagram of the experimental set up

The well collimated beam of photons from the source S was made to fall on the target T mounted on the target holder. The detector D to Target T distance was 28 cm and the Target to Source was 35 cm. The detector D received the scattered gamma rays. The gamma ray beam was properly shielded by lead throughout its journey from the source to the detector and care was taken to minimize the background radiation. The entire experiment was carried out in an air- conditioned room wherein the mains' voltage was stabilized in order to minimize the channel drift. The thickness of the Steel samples ranged from 39 to 42 g /cm^2. The experiment was then repeated with the ^{203}Hg and ^{65}Zn sources, which emit 279.1keV and 1115.5keV gamma rays respectively. These two sources were procured in the form of radiographic capsules from the Bhabha Atomic Research Centre (BARC), Mumbai, India.

An ORTEC model 23210 gamma-x high purity germanium detector (HPGe) has been used to record the data along with a personal computer based multi channel analyzer. The counts under the peak (scattered intensity) were determined accurately after subtracting the background counts by applying Gaussian fitting. A typical background subtracted spectrum obtained with Steel 1 sample at 661.6keV is as shown in Figure 2. The differential incoherent scattering cross sections of the Steel alloys so obtained at the three scattering angles 60°, 80^0 and 100°, at the three energies 279.1keV, 661.6keV and 1115.5keV are given in Table 2 along with the experimental errors. The error analysis and the evaluation of differential incoherent scattering cross sections of the steel alloys were performed by following a procedure similar to our earlier work [4].

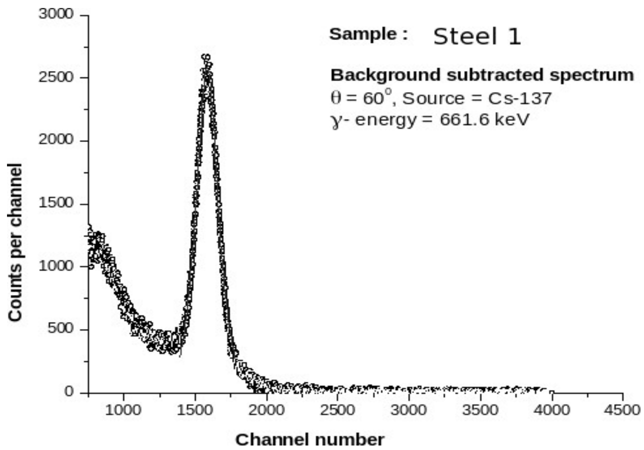

Figure 2. Typical background subtracted scattered spectrum for Steel 1 at 600 and 661.6keV

The incoherent scattering cross sections were further used to calculate the effective atomic number of these steel samples by following a procedure described in our earlier paper [4]. These values have also been listed in Table 2. It was observed from Table 2 that all the steel samples used could be represented by a mean effective atomic number of 25.85 for Compton effect. The errors in the present measurements are mainly a result of counting statistics. The error due to counting statistics was kept below 0.3 % by accumulating 10^5-10^6 counts within the photo peak of the scattered spectrum. The other sources of errors are also described below.

Table 2: Differential incoherent scattering cross sections (milli barn / mol / steradian) and effective atomic number Z_{eff} of some Steel Alloys (Experimental errors are to the extent of 2%-3%)

Steel Alloys	*θ= 60°*			*θ= 80°*			*θ= 100°*			*Mean Z_{eff}*
	279.1 keV	*661.6 keV*	*1115.5 keV*	*279.1 keV*	*661.6 keV*	*1115.5 keV*	*279.1 keV*	*661.6 keV*	*1115.5 keV*	
Steel 1	829.1 25.9	570.7 25.9	488.6 25.9	559.4 25.4	379.3 25.9	314.9 25.9	437.2 26.5	286.2 25.9	232.6 25.9	25.9
Steel 2	825.1 25.8	573.7 26.0	490.6 26.0	555.2 25.3	379.9 25.9	315.9 26.0	436.3 26.4	287.4 26.0	233.0 25.9	25.9
Steel 3	827.3 25.8	573.0 26.0	489.7 25.9	557.4 25.3	380.0 25.9	314.0 25.8	432.3 26.2	285.5 25.8	232.0 25.8	25.8
Steel 4	828.3 25.9	571.0 25.9	488.7 25.9	558.3 25.4	381.1 25.8	313.0 25.7	432.2 26.2	286.4 25.9	232.5 25.9	25.8
First line: Differential incoherent scattering cross sections; Second line: Effective atomic number Z_{eff}										

The error associated in evaluating the area of the scattered peak by the peak fitting routine was less than 1%. The error in the determination of the number of atoms in the scatterer was negligible. In the present measurements, care was taken to maintain the same diameter for all the samples. They differed only in their heights. Therefore, the angle of acceptance was almost the same in each measurement. Errors due to multiple scattering effects were negligible during the present study. The uncertainty in calculating the transmission factors using the transmitted intensities was less than 1%. The percentage dead time correction was always less than 2% in the present study. Thus, the overall error in the present measurement was to the extent of 2% to 3% on the measured values.

Conclusions:

Thus, it has been possible in the present study to obtain the differential incoherent scattering cross sections of some Steel alloys at three gamma ray energies 279.1, 661.6 and 1115.5keV by employing a high resolution high purity germanium detector at the three scattering angles 60^0, 80^0 and 100^0 respectively. The effective atomic number of these alloys for Compton effect has also been determined using these cross sections. *It was found that for all the steel samples used are characterized by a mean effective atomic number of 25.85 for Compton Effect.* To the knowledge of the authors the results obtained in the present study are the first of their kind at these energies over this angular range.

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