Measurement of the incoherent scattering cross sections and average effective atomic numbers of some Sodium salts by Gamma Irradiation for commercial applications

Prasanna Kumar S*
Department of Physics, JSS Academy of Technical Education, JSS Campus,
Dr. Vishnuvardhan Road, Bangalore-60
Sankarshan BM
Department of Physics, NIE, Mysuru
Umesh TK
Department of Studies in Physics, University of Mysore, Mysuru

*prasannakumars@jssateb.ac.in

Abstract

In this paper we report the measurement of incoherent scattering cross section and the effective atomic number of some salts of sodium for the Compton effect in the gamma ray energy range 280-1115 keV at 60^0, 80^0 and 100^0. The salts of sodium used in the present investigation are NaCl, $NaNO_2$, $NaHCO_3$, Na_2CO_3, Na_2SO_4, NaF are used widely in the food preservatives, soaps, detergents, drying agents to cleaning agents. The measured values of the incoherent scattering cross sections are in good agreement with the literature available. These results were further used to evaluate the effective atomic numbers of these salts. To our knowledge, the results of the effective number so obtained are first of its kind and rarely available in the literature, may find its use in the different fields of science and as well in industry.

Keywords:-Incoherent scattering cross section, Gamma irradiation, Compton effect, Effective atomic number,

I. INTRODUCTION

There are plenty of chemicals in their actual form or along with other substitutes are used in every body's daily life. It may be started from table salt (NaCl), sugars, soaps and detergents (Na_2CO_3, Na_2SO_4), baking powder ($NaHCO_3$), mouth wash, tooth paste (NaF), vinegar etc. Like we keep the benefits of chemicals in our life, we must also take care to treat them with respect so as to reduce the potential harm impact from exposing them. In addition we should always try to explore the new opportunities and possibilities to enhance the living standards of the consumers.

The technological advancements have led to the use of radiation sources (x-rays and gamma sources) in the different fields of human enterprises. When radiation interacts with the matter, the scientific community will prefer to understand this interaction of radiation with elements and to all other materials in terms of interaction cross sections. When a cross section is specified as a function of some final-state variable, such as particle angle or energy, it is called a differential cross section, but when a cross section is integrated over all scattering angles it is called a total cross section.

Scattering cross sections may be defined as the collisions of accelerated beams of one type of particle with the targets of other type of particle. The probability for any given reaction to occur is in proportion to its cross section. Differential and total scattering cross sections are the most important measurable parameters in nuclear, atomic and particle physics [1].

Differential scattering cross sections help us to comprehend the physical interactions between the energy of the photons and physical properties of the target. It represents the ratio of intensity of the incident radiant energy scattered in a given direction to the incident radiation per unit area. The results could be further used to measure effective atomic number Z_{eff}, electron density N_{eff} and Compton profiles and so on.

II. Theory

Calculation of Differential Incoherent Scattering Cross Sections:

The whole atom differential incoherent scattering cross section for an element of an atomic number Z at an angle θ is given by the equation

$$\left(\frac{d\sigma}{d\Omega}\right)_{Incoh} = \frac{n_{sc}}{n_i \; N} \tag{1}$$

where n_{sc} is the number of photons scattered into the cone of solid angle dΩ at an angle θ. n_i is the number of photons incident on the target and N is the number of atoms present in the scatterer. To calculate n_{sc} and n_i the values of the photo-peak efficiency, solid angle and source strength are essential. The estimation of these quantities is not only tedious but involves large errors. Hence, in the present investigation, the incoherent scattering cross-sections were determined by treating aluminum as a pure Compton scatterer as there are no pure electron binding effects for aluminum at the incident photon energy used in this investigation. Thus the experimental whole atom differential incoherent scattering cross section is calculated by using the equation.

$$\left(\frac{d\sigma}{d\Omega}\right)_{Incoh} = \left(\frac{d\sigma}{d\Omega}\right)_{kn} S(q, Z = 13)\frac{n_{sc}}{n_{Al}}\frac{T_{Al}}{T}\frac{N_{Al}}{N} \tag{2}$$

where $\left(\frac{d\sigma}{d\Omega}\right)_{Incoh}$ is the differential incoherent scattering cross section, $\left(\frac{d\sigma}{d\Omega}\right)_{kn}$ is the free electron Klein-Nishina (KN) cross section (1929) [2]. S (q, Z = 13) is the incoherent scattering function of the aluminum target taken from the tabulation of Hubbell et al (1975). n_{sc} is the area under the incoherent scattering peak for the target, n_{Al} the corresponding area under the incoherent scattering peak of aluminum. T_{Al} and T are the transmission factors for aluminum and the targets respectively for the Compton scattered gamma ray energies. N_{Al} and N are the number of scattering atoms for aluminum and the target respectively.

A more convenient expression for the equation (2), in the impulse approximation can be expressed as in terms of the observed bound incoherent scattering cross sections and the free electron of KN cross sections as,

$$\sigma_b(\theta) - \sigma_{KN}(\theta) \; S(q, Z) \tag{3}$$

Where,

$\sigma_b(\theta) = \left(\frac{d\sigma}{d\Omega}\right)_{incoh}$, and $\sigma_{KN}(\theta) = \left(\frac{d\sigma}{d\Omega}\right)_{KN}$ are the usual bound and the Klein-Nishinna cross section in millibarn per electron per steradian respectively, Z is the atomic number and S(q, Z) is the incoherent scattering function, in which 'q' is a momentum transfer variable dependent on the incident photon energy and the scattered-photon deflection angle, and Z is the atomic number of the atom associated with the target electron.

Here in the present investigation, when the electron is completely free from atomic binding effects S(q, Z) will be equal to Z [3]. If the scatterer is a composite material or a mixture, then Z is definitely its effective atomic number Z_{eff}.

$$Z_{eff} \approx Z = \frac{\sigma_b}{\sigma_{KN}} \quad (4)$$

III. Experiment and Result

In the present investigation, the study of the angular distribution of scattered gamma rays was done using a goniometer employing with collimator type geometry. A schematic diagram of the experimental setup used in the present investigation is given in Figure 1. It consists of three different parts, namely *source holder, target holder* and *the detector holder.*

The *source holder* is made up of lead cylinder of 7.5cm diameter and 16cm in length in addition to a pin hole collimator having diameter 1.1cm. The source holder rests on a movable arm and can be fixed to any distance from the center of the scatterer and to any angle with respect to the direction of the axis of detector. The distance between the source and the target was 35cm. With the help of a laser torch the source holder was arranged to be coaxial with the center of the target.

The *target holder* made of Perspex material is such that the height of the holder can be varied and fixed in any desired position. Removing or replacing the target can also be accomplished with ease. The target holder is fixed to an iron rod, which is in turn fixed to the movable arm carrying the source holder. The complete assembly has the same vertical axis passing through the center of the scatterer such that the correct rotation to the source holder about the vertical axis is ensured.

The *detector holder* was fixed and the detector was shielded by lead cylinders lined inside with aluminum. A collimator was introduced between the scatterer and the detector, having a diameter of 13cm and thickness 4.5cm. The collimating hole had a diameter of 1cm, and was kept at distance of 8.5cm from the scatterer. The total distance between the scatterer and the detector was 28cm.

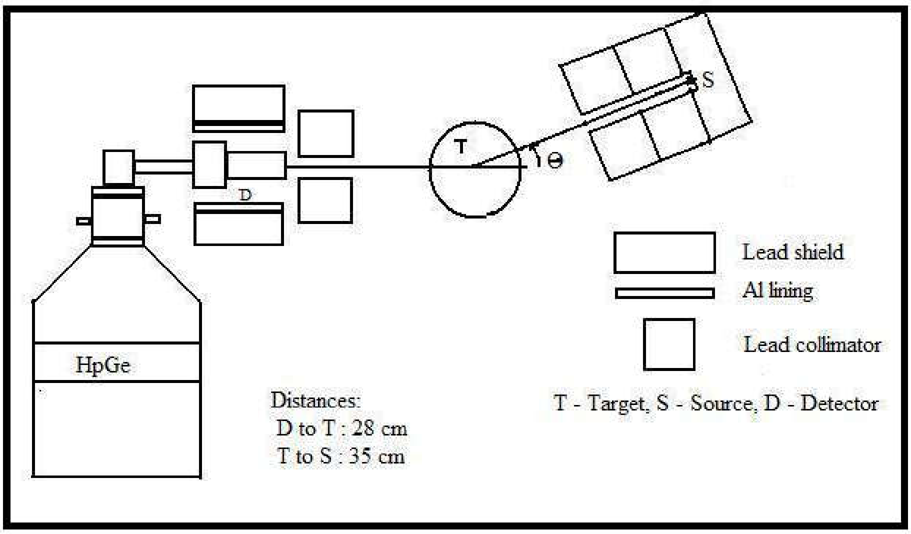

Figure. 1. Experimental setup

The source holder, the collimator holder and the detector shielding were effectively placed away from the walls to minimize the scattering from the floor and the wall. The geometrical set up of the experiment was performed with the help of a precision cathetometer. The opening of the source holder was initially covered with an easily removable Bakelite disk that fits it exactly. This was provided with a fine central hole. The telescope was then focused on the fine hole. Subsequent adjustments necessary to make the centre coincide with the cross wires were achieved by suitably moving the telescope sideways or by adjusting the height. The detector opening was similarly covered with a Bakelite disc, keeping the position of the telescope unaltered, the detector shield was adjusted adequately so as to coincide with the fine central hole again with the cross wires. Final adjustments were made by covering both the holes with Bakelite discs, illuminating one of the openings by a lamp and observing the transmitted light at the other end of the telescope. This alignment was also verified by using a laser torch.

A list of the samples of the sodium salts with their purities and the manufacturers and suppliers are given in Table 1. The solid samples were ground into a fine powder and pressed into solid pellets. The mass per unit area of the sample pellets ranged between 32 to 52 g/cm^2.

Table 1. Purity, molecular weight and suppliers of the samples

Compound	Molecular weight	Percentage purity	Manufacturers/Suppliers
NaCl	58.44	99.90	Sarahai-Merck Pvt, Ltd
$NaNO_2$	68.995	99.80	Sarahai-Merck Pvt, Ltd
$NaHCO_3$	84.007	99.00	British Drug Houses Ltd
Na_2CO_3	105.998	99.00	E.Mereck, Germany
Na_2SO_4	142.04	99.90	British Drug Houses Ltd
NaF	48.988	99.80	Allied Chemicals, USA

3.1 Gamma Ray Source and the Detection System:

The radioactive isotope ^{137}Cs emitting 661.6keV gamma ray was procured from Radiochemical Center, Amersham, U.K,. The other radioactive sources ^{203}Hg and ^{65}Zn, which emit 279.1 keV and 1115.5 keV gamma rays respectively, used in the present investigations, were obtained in the form of radiographic capsules from the Bhabha Atomic Research Centre, Mumbai, India.

The detection system includes the photon detector, bias supply, preamplifier, spectroscopic amplifier and a multichannel analyzer (MCA). A high purity germanium detector (HpGe) with high resolution and optimum efficiency was employed in the scattering experiment. The detector has a resolution of 2.1 keV at 1332.5 keV and 23% efficiency. Unlike Ge (Li) detectors, HpGe detector is disconnected from all external circuits may be warmed up to room temperature and stored for any desired period and then cooled again. So it is enough to cool it and keep at liquid nitrogen temperature only during the actual course of the experiment. However special care has to be taken during each first cooling to see that the high voltage is applied only after a minimum of six hours cooling time. The operating voltage of the detector was 2500 volt.

3.2 Experimental details:

A well collimated beam of photons from the radioactive sources S was made to incident on the target T mounted on the target holder as in Figure 1. The scattered radiations from the target are received by an ORTEC model 23210 gamma-x HpGe detector. The gamma ray beam was properly shielded throughout its journey from the source to the detector.

The experiment was performed at three different scattering angles 60^0, 80^0, and 100^0 for three different radioactive sources of energy 279.1 keV, 661.6 keV and 1115.5 keV.

The net scattered photons received at the detector are further processed for actual counts. The accurate counts under the peak were determined by subtracting the back-ground counts using a PC-based multi-channel analyzer after applying Gaussian fitting technique. A sample photo-peak after subtracting for background noises for NaCl sample at scattering angle 60^0 and incident gamma radiation energy 661.6 keV is observable in the Figure 2.

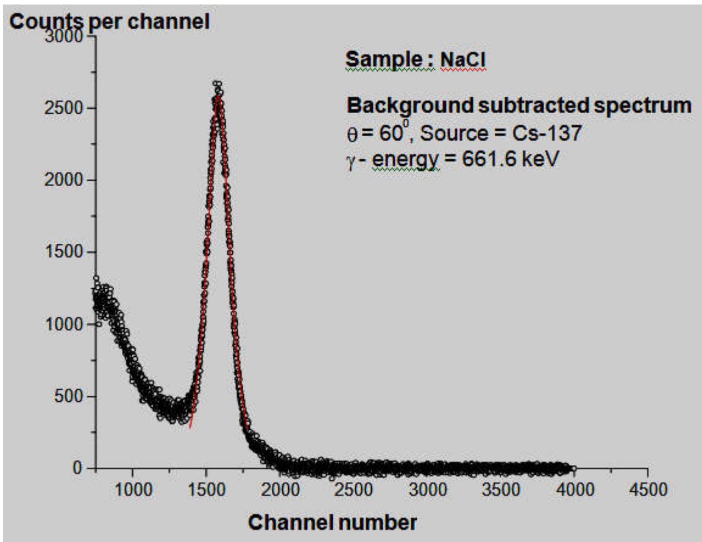

Figure2: Back ground subtracted spectrum for NaCl at 60^0 and at 661.6keV

The differential incoherent scattering cross sections of the samples under investigation were carried-out in an air-conditioned room where the mains voltage was stabilized to minimize the channel drift. The obtained incoherent scattering cross sections are used further to obtain the average effective atomic numbers as tabulated in Table 2. The errors in the present investigation was about 0.3% due to counting statistics, since the data acquisition was 10^5-10^6 counts within the photo peak of the scattering spectrum.

Table 2: Incoherent scattering cross sections (millibarn/atom/steradian) and effective atomic number (experimental errors are to the extent 2-3%)

Material	279.1keV			661.1keV			1115.5keV			Avg Zeff
Angle→	60	80	100	60	80	100	60	80	100	
NaCl	896.9	617.4	528.6	615.8	410.5	340.8	462.1	309.6	251.6	27.9
$NaNO_2$	1089.3	749.8	641.8	747.8	498.5	413.8	561.2	375.9	305.5	33.9
$NaHNO_3$	1345.6	926.2	792.8	923.8	615.8	511.2	693.2	464.4	377.4	41.9
Na_2CO_3	1665.9	1146.7	981.6	1143.7	762.5	632.9	858.3	575	467.3	51.7
Na_2SO_4	2242.6	1543.7	1321.4	1539.7	1026.4	852.1	1155.4	774	629	69.2
NaF	640.7	441	377.5	439.9	293.2	243.4	330.1	221.1	179.7	19.8

IV. CONCLUTION

The experimentally measured incoherent scattering cross sections are used further to obtain the average effective atomic numbers Z_{eff}. The effective atomic number is calculated from equation (4). In the present range of energy and scattering angles, since the samples being inorganic compounds, the effective atomic numbers remains constant [4]. It is found from the Table 2, that the sample NaF has least average effective atomic number is 19.8 and Na_2SO_4 has highest value of 69.2 for its effective atomic number. Higher the value of Z_{eff}, gives the valuable information regarding the stability of complex salts and also help in better understanding if the compound has reducing or oxidizing properties. This result may play a vital role in exploring the better opportunities by the industry for enhanced performances. To our knowledge, the results of the effective number so obtained are first of its kind and rarely available in the literature. The data so obtained may be used to estimate electron densities and Compton profiles of samples may find its application in industry and other fields of science and technology.

Acknowledgements:

The authors express their immense gratitude to the University of Mysore, Mysuru for providing all the necessary facilities to carry out the present investigation. One of the authors (SPK) would like to thank the management of JSSATE, Bengaluru for the continuous support and encouragement in carrying out the present investigation.

References

1. R. G. Newton. **Scattering Theory of Waves and Particles**. McGraw Hill, 1966.

2. O. Klein and Y. Nishina , **über die Streuung von Strahlung durch freie Elektronen nach der neuen relativistischen Quantendynamik von Dirac**. Zeitschrift für Physik, 52, 853-868.

3. S. Prasanna Kumar, V. Manjunathaguru and T.K.Umesh, **Effective atomic number of some H-, C-, N- and O- based composite materials derived from differential incoherent scattering cross sections,** , Pramana - Journal of Physics, 74(4), (2010), pp 555-562.

4. S.Prasanna Kumar and T.K.Umesh**, Experimental measurement of effective atomic number of composite materials for Compton effect in the photon energy range 280-1115keV by a new method** , Pramana - Journal of Physics 77(2), (2011), pp 335-344