

**STUDIES ON THE WHOLE-ATOM INTEGRAL  
INCOHERENT SCATTERING  
CROSS SECTIONS FOR GAMMA RAYS**

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*THESIS SUBMITTED TO THE UNIVERSITY OF MYSORE  
FOR THE DEGREE OF*

**DOCTOR OF PHILOSOPHY**

**IN PHYSICS**

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**1994**

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DECLARATION

The author declares that this work is original and carried out in the Department of Studies in Physics, University of Mysore, Manasagangotri, Mysore-570 006, India. This work or any part of it has not been submitted for a higher degree either in this University or in any other University.

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## ACKNOWLEDGMENTS

I acknowledge with sincere thanks and profound sense of gratitude, the stimulating guidance, constant encouragement and untiring supervision that I have received from Dr. Ramakrishna Gowda, Reader in Physics, Department of Studies in Physics, University of Mysore, Mysore, during the course of the present investigation. His valuable support and timely suggestions have enabled me to successfully complete the arduous task of preparing this thesis.

Women, Hassan, for lending me some of the chemical compounds used in the present investigation.

I am extremely grateful to Dr. T.K. Umesh, Reader in Physics for his guidance and many constructive suggestions throughout the course of these investigations and for assistance in preparing the thesis.

My special thanks must be accorded to Prof. J. Shashidhara Prasad and Prof. S. Gopal for their constant encouragement during the period of investigation.

I wish to thank my teachers Prof. K. Gopal, Prof. P. Venkataramaiah, Dr. K. S. Puttaswamy and Dr. C. Ranganathaiah for their constant encouragement.

It is with great pleasure that I thank Smt. S. J. Anasuya, Sri. Channe Gowda, Sri K. P. Gopinathan Nair and Mr. Sandiago for their help at various stages of this work and for their co-operation.

My thanks are also due to Dr. B. Basavalingu, Department of Geology, for lending me some of the chemical compounds used in the present investigation and the help rendered at various stages of this work.

The author is thankful to University Grants Commission and College Development Council for having extended the teacher fellowship, for the year 1992-93.

I would be failing in my duty if I do not express my thankfulness to our College Management, College Principal Prof. Usha Krishna Murthy and Head of the Physics Department, M.K.Subbalakshmi, A.V.Kanthamma College for Women, Hassan, for providing me an opportunity to complete this work.

I thank my Husband Sri Hemaraju, for his encouragement and constant support throughout this work.

## PREFACE

Interaction of gamma rays with matter has drawn wide ranging attention in the fields of science and technology. Compton (incoherent) scattering is one of the fundamental modes of interaction between gamma radiation and matter. This is significant especially in the energy region 200 keV to 2000 keV. The data on incoherent scattering cross section are very important in industrial radiography, radiation attenuation, reactor shielding, transport, weapon effects and in various other fields.

The incoherent scattering is that scattering of gamma rays in which the energy of the scattered photon is less than that of the incident photon. It is described as a second order process involving initial, intermediate and final states of an electron. Since the final state of an electron may be any one in the continuum, the precise calculation of the incoherent scattering cross sections is very tedious. In recent years, however there have been renewed efforts to evaluate the incoherent scattering cross sections of elements.

Different non-relativistic calculation of compton scattering cross sections for bound electrons have been performed using various atomic models to estimate the incoherent scattering cross sections. These calculations include a correction factor for Klein-Nishina formula for the free electron. This correction factor is expressed in terms of what is called an incoherent scattering function  $S(q,z)$  which expresses the probability that ionised state when an incident photon transfers momentum to any one of the atomic electrons.

Most of the theoretical investigations have been centered around the calculation of  $S(q,z)$  by assuming different models for atomic charge distribution. Among them the Thomas-Fermi model [veigle, 1973] and the Hartree-Fock model [Hubbell et al, 1979] have been widely used. Hubbell et al (1975) have calculated the differential and integral incoherent scattering cross sections of elements in the atomic range  $Z = 1$  to 100 in the energy region 100 eV to 100 MeV using self consistent field Hartree-Fock bound electron wave functions. Recent review of Kane (1992) covers both the theoretical and the experimental developments in the study of bound electron incoherent scattering cross sections in the photon energy range from 2 keV to 1 MeV. The main focus is on both non-resonant inelastic scattering by strongly bound electrons.

Recently, Bergstrom et al (1993) have reported theoretical work on incoherent scattering that goes beyond the incoherent scattering function approximation. In this work, Compton scattering from bound electrons is studied within external field quantum electrodynamics and the independent particle approximation but without making use of any additional approximations, such as impulse or incoherent scattering factor approximations. The calculation done by them is of the doubly differential cross sections for scattering of unpolarized and polarized photons from bound atomic electrons as a function of scattered photon energy and angle, based on a numerical evaluation of the second order S-matrix in self-consistent screened atomic potentials. The authors also discuss the cross section singly differential in scattered photon angle, emphasizing the contribution of terms neglected when making the incoherent scattering factor approximation as well as implication for total cross sections and for attenuation coefficients.

Experimentally, most of the investigations are oriented towards the calculation of  $S(q,z)$ . The experiments carried out so far can be classified into two classes, (1) measurements on differential incoherent scattering cross sections (2) measurements on integral incoherent scattering cross sections.

Determination of the whole-atom integral incoherent scattering has been done by two methods the subtraction method and the linear extrapolation method.

In the subtraction method, the integral incoherent scattering cross sections of elements are obtained by subtracting the theoretical contributions of other competing processes such as photoeffect, coherent scattering and the pair production from the measured total attenuation cross sections. This method is justified in the photon energy region where the contributions from other competing processes to the attenuation cross section is relatively small and could be treated as corrections. Also the accuracy of this method depends seriously on the accuracy of the subtracted theoretical contributions.

In the extrapolation method, the total attenuation cross sections of elements are derived from their respective chemical compounds. The derived cross sections of various elements are plotted against the atomic number at each energy. These plots are found to be linear in the low  $Z$  region. Making use of this linear portion a straight line is fitted and this line is extrapolated towards the high  $Z$  region. The whole-atom integral incoherent cross section of high  $Z$  elements are thus obtained from this extrapolation. This method although is not dependent on theory, however depends on how accurately the low  $Z$  total attenuation cross sections are determined.

Thus, in the light of above, we have developed a new simple experimental method from which one can directly obtain the integral incoherent scattering cross sections of elements or the simple chemical compounds of those elements. For the purpose, a well type NaI(Tl) crystal detector was chosen. The samples were kept inside the well of the detector. The total attenuation cross sections were calculated using the transmitted spectra with and without the samples in the path of the photon beam. The plots were made to extract the incoherent scattering cross sections of the samples. In the case of chemical compounds the whole-atom integral incoherent scattering cross sections of their elements can be obtained by using the mixture rule.

The content of the thesis is divided into five chapters. The brief description of each chapter is given below.

The chapter I contains a survey of both theoretical and experimental work. At the end of this chapter the motivation to take up the present experimental work is presented.

Chapter II deals with a brief discussion on photon interactions with matter and the theoretical resume on incoherent scattering cross section.

In chapter III a detailed account of the present experimental set up is given. This includes the description of the detector along with the associated electronics. Details regarding the sources and the samples used in the present investigation are also given.

Chapter IV includes a detailed description of the method of estimating the whole atom integral incoherent scattering cross sections.

Chapter V deals with the results and discussion of the whole atom integral incoherent scattering cross sections. The possible conclusions drawn are also included.