STUDIES ON GAMMA ATTENUATION AND PHOTOELECTRIC EFFECT USING ^{241}Am GAMMA RAYS

Thesis submitted to the University of Calicut

In partial fulfillment of the requirements

for the Degree of

DOCTOR OF PHILOSOPHY

IN PHYSICS

By

N.RAMACHANDRAN

DEPARTMENT OF PHYSICS
UNIVERSITY OF CALICUT

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TO

MY PARENTS

TEACHERS

AND

MY CHILDREN

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Dr. K. M. Varier
Professor

Department of Physics
University of Calicut

CERTIFICATE

This is to certify that this thesis entitled `Studies on gamma attenuation and photoelectric effect using ^{241}Am gamma rays' is a bonafide record of research work carried out by **N.RAMACHANDRAN** under my supervision in the Department of Physics, *University of Calicut, for the award of the Ph. D degree of University of* Calicut and that no part of this thesis has been presented elsewhere for the award of any degree, diploma or other similar title.

Calicut University

8th August 2003

K M Varier

(Dr. K. M. Varier)

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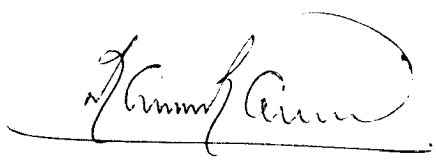
DECLARATION

I hereby declare that this thesis entitled ` Studies on gamma attenuation and photoelectric effect using ^{241}Am gamma rays' is a bonafide record of research work done by me and that no part of this thesis has been presented before for the award of any degree or diploma.



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ACKNOWLEDGEMENTS

I express my deep and sincere gratitude to Dr. K. Muraleedhara Varier, Professor, Dept. of Physics, for suggesting this problem and for guiding me throughout the research work. He has always been a source of inspiration and encouragement to me.

I wish to express my sincere thanks to Dr. K. Neelakandan, Professor and Head of the Department of Physics, for providing the necessary facilities during the research period, and for his encouragement.

I am thankful to the Principal and management of S.N.G.College, Chelannur, for giving necessary permission for me to do this work at the Department of Physics, University of Calicut.

Suggestions and help from Dr. Antony Joseph, Dr. A.M. Vinod Kumar, Sri. K. Karunakaran Nair and Sri. B.P.Ajith Kumar are greatly acknowledged.

I am grateful to the Director, Nuclear Science Centre, New Delhi, for providing the CAMAC interface and the necessary software (FREEDOM).

Thanks are also due to Dr. K.Devan, Scientific Officer, Reactor Physics Division, IGCAR, Kalpakkam for arranging the necessary reference facilities at the IGCAR Library.

I would like to express my sincere thanks and gratitude to Dr.K.Krishnankutty, Professor, Department of Chemistry, University of Calicut for giving necessary assistance and for supplying certain valuable chemicals during my research work.

I am also expressing my deep gratitude to Dr. E.Nabeesa Salim, Reader, Department of Botany, University of Calicut for providing their oven and also for her kind help while doing my experiments.

Thanks are also due to Dr. M. P. Kannan, Head of the Department of Chemistry, University of Calicut, for providing the sieves of various mesh sizes for carrying out the studies on gamma attenuation in soil and sugar samples. Also, I thank Sri. Balakrishna Pillai, Instrumentation Engineer–in–charge, University Scientific Instrumentation Centre, Calicut University for the loan of a Pelletizer.

I hereby express my sincere thanks to the University Grants Commission, Government of India, for providing a fellowship under the FIP program.

I owe my thanks to all members of the teaching and non-teaching staff in the Department of Physics, University of Calicut, for their cooperation.

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CHAPTER I

INTRODUCTION

Gamma rays are electromagnetic radiations of very high frequencies. When gamma rays pass through matter, their intensity is attenuated according to the exponential law. This means that a beam of radiation of a definite energy E_γ having intensity I_o, passing through an absorber of thickness x will have a transmitted intensity given by [1]

$$I(x) = I_o e^{-\mu x} \qquad \text{.....(1.1)}$$

where μ is a constant characterizing the medium for that gamma energy. It is called the linear attenuation co-efficient. If x is in cm, μ will be expressed in units of cm^{-1}. The mass attenuation coefficient is expressed as μ/ρ where ρ is the density of the medium. It is more common to express the thickness of the absorber as $t = x\rho$ and the mass attenuation coefficient is then given in units of cm^2/g. The absorption law can be rewritten as

$$I(t) = I_o e^{-\mu t} \qquad \text{.....(1.2)}$$

The linear absorption co- efficient μ depends on the gamma ray energy E_γ, the atomic number Z and the density ρ of the absorber medium .On the other hand, the mass attenuation co-efficient μ / ρ is independent of the absorber density. For a mixture or a compound of different elements, the mixture rule [2] applies. According to this, the mass attenuation co-efficient is given by the equation

$$\mu/\rho \;=\; \Sigma f_i \, (\mu / \rho)_i \qquad \text{...(1.3)}$$

where f_i is the weight fraction of the i^{th} element with mass absorption coefficient $(\mu / \rho)_i$.

When a γ ray photon interacts with an atom, there is a finite probability that the whole of the photon energy is completely absorbed by the atomic electrons. Part of this energy may be used to overcome the binding of the electrons to the atom and the remaining energy will be converted into the kinetic energy of the electron. It can be represented by the simple equation

$$E_e \;=\; E_\gamma \;-\; B \qquad \text{............................(1.4)}$$

where B is the binding energy of the electron in the atom. This process is known as photoelectric effect. It will not take place with a free electron, as it would not be possible to conserve energy and momentum. The cross section for photoelectric absorption in the K shell of an atom with atomic number Z is proportional to $Z^5 / E_\gamma^{7/2}$. Thus the process is more predominant at lower energies (up to 500 keV) and for heavy elements.

Pair production involves the complete absorption of gamma ray photon in the field of nucleus of an atom or an electron. During this absorption a pair of electron and positron will be produced. The condition for pair production is that the energy of the photon must be greater than $2m_oc^2$ (1.02MeV), the total rest mass energy of the pair. The pair production cross-section increases with the atomic number of the absorber as Z^2.

When the energy of the incident gamma ray photon exceeds the separation energy of proton or neutron, photonuclear absorption takes place. It is also called nuclear photo effect. This process is negligible if the photon energy is less than about 10 MeV. If the energy of the incident photon is greater than 150 MeV, then the process of photo meson production will start. But the cross sections are extremely small.

The other mode of interaction of gamma ray photons with matter is scattering. There are two types of scattering (a) elastic scattering (b) inelastic scattering. In the case of elastic scattering, both momentum and kinetic energy of the particles are conserved. Hence the energy of elastically scattered gamma ray photon is nearly same as the incident energy. There are four types of elastic scattering. The scattering from bound atomic electrons is called Raleigh scattering. This process is predominant in the region around and below 1 MeV and is more effective at small scattering angles. Coherent scattering from the nucleus as a whole is called Thomson scattering. When a beam of photons passes near an electron, this electron is momentarily accelerated by the electric field of the wave and so radiates energy. It is independent of energy and is proportional to Z^4.

In the case of nuclear resonance scattering the nucleus of an atom is excited due to the incident photon energy. Subsequently there will be re emission of the excitation energy when the excited nucleus decays to the ground state. The scattering cross section varies as Z^2. This process is more predominant in the regions of narrow resonance maxima at low energies and broad maxima in the range of 10-30 MeV.

When the gamma ray photon interacts with the coulomb field of the nucleus another type of scattering process can take place. This process is called Delbr uk scattering.

Inelastic scattering of gamma ray photons by a free electron is called the Compton scattering. In this process some energy is scattered and some is transferred to kinetic energy of the struck electron. This process dominates in the energy region of around 1 MeV. It decreases as energy increases. For very low energy photons, the Compton scattering cross section is same as that of Thomson scattering cross section. The cross section varies as Z.

When a beam of gamma rays passes through an absorber, the gamma ray photons interact with the atoms individually and are either absorbed (via photoelectric effect and pair production) or scattered away from the beam. The intensity of the transmitted beam is consequently attenuated. The total cross section for attenuation of the incident beam of γ –rays is the sum of the cross sections per atom for all the three processes. Therefore, the total cross section is given by

$$\sigma = \sigma_{ph} + Z\,\sigma_c + \sigma_{pair} \qquad \text{.....(1.4)}$$

If N is the number of atoms per unit volume of the absorber, the linear absorption coefficient

$$\mu = \sigma N \qquad \text{.....(1.5)}$$

The total attenuation coefficient can be measured experimentally by simple absorption measurements. In order to find the value of μ we have to know the initial intensity of the incident γ - ray photon. The absorption of γ – rays depends strongly upon its energy and the atomic number of the absorber. The exponential absorption law (equation 1.1) is difficult to observe experimentally because of the detection of the gamma rays scattered from the absorber and other surroundings along with the transmitted beam. The X – rays emitted from the absorber also affect the measurements. In order to reduce the above mentioned problem we have to use a narrow beam geometry set up [2]. This arrangement reduces the solid angle subtended by the detector at the center of the target by use of suitable shielding and collimation. It prevents the coherently and incoherently scattered photons from reaching the detector. Hence only the radiation coming out from the target without any interaction will reach the detector.

Photon attenuation and photoelectric effect data are very essential in many fields of research areas. It is very relevant in studies of radiation transport and shielding. The photoelectric absorption cross section close to the absorption edge is very important in radiation physics and it has lot of application in medical field.

The main intention of the present studies has been to determine the total attenuation coefficients of various rare earth elements using 59.54 keV gamma rays from Amrecium-241 source. This gamma energy is quite interesting since it comes in between the K-edge energies of the rare earth elements from Ce to Yb. Also, another equally important purpose has been the determination of the photoelectric cross sections of the

rare earth compounds by using Americium-241. By using the same experimental setup and the detector, the water content of fresh and dried wood and leaf samples were also investigated. With the help of ^{241}Am source, the effect of the grain size of various soil samples of the beaches of Calicut and Neendakara were investigated. The present thesis gives the details, results and discussions of the experimental investigations.

In the following, various gamma ray interactions with matter are reviewed in detail in Chapter II. Some previous experimental and theoretical studies on gamma ray attenuation and photoelectric effect are described in Chapter III. In the subsequent chapters IV and V, the present experimental studies on attenuation and photo electric absorption have been described in detail. Investigations have been carried out using oxides of some rare earth elements. For the attenuation studies, both aqueous solutions and pellets have been used as absorbers. For the photoelectric measurements, the pellet targets have been used. Chapter VI presents the experimental details and the important results obtained from the gamma attenuation studies on fresh and dried leaf and wood samples. In Chapter VII a detailed discussion of the results of the present investigations on absorbers with various particle sizes, is provided along with conclusions drawn there from.

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CHAPTER II

GAMMA RAY INTERACTIONS

2.1 Introduction

When a beam of gamma rays passes through matter its intensity is reduced. The beam is attenuated and some of the energy that it originally possessed is taken up or absorbed by the irradiated material. The remaining part of the energy is simply deflected out of the beam to travel on in some new direction as scattered radiation. Each of these processes play a vital role in Radiation Physics , Radiology and Nuclear Physics.

The intensity of the photon beam decreases exponentially as it traverses the material. The variation with the distance t traversed is given by the relation

$$I = I_o e^{-\mu t} \qquad \text{.....(2.1)}$$

where μ is a characteristic property of the material called the attenuation coefficient

The attenuation coefficient is a function of energy for a given material. For mono energetic gamma rays, the intensity decreases exponentially with thickness of the target (Fig 2.1).

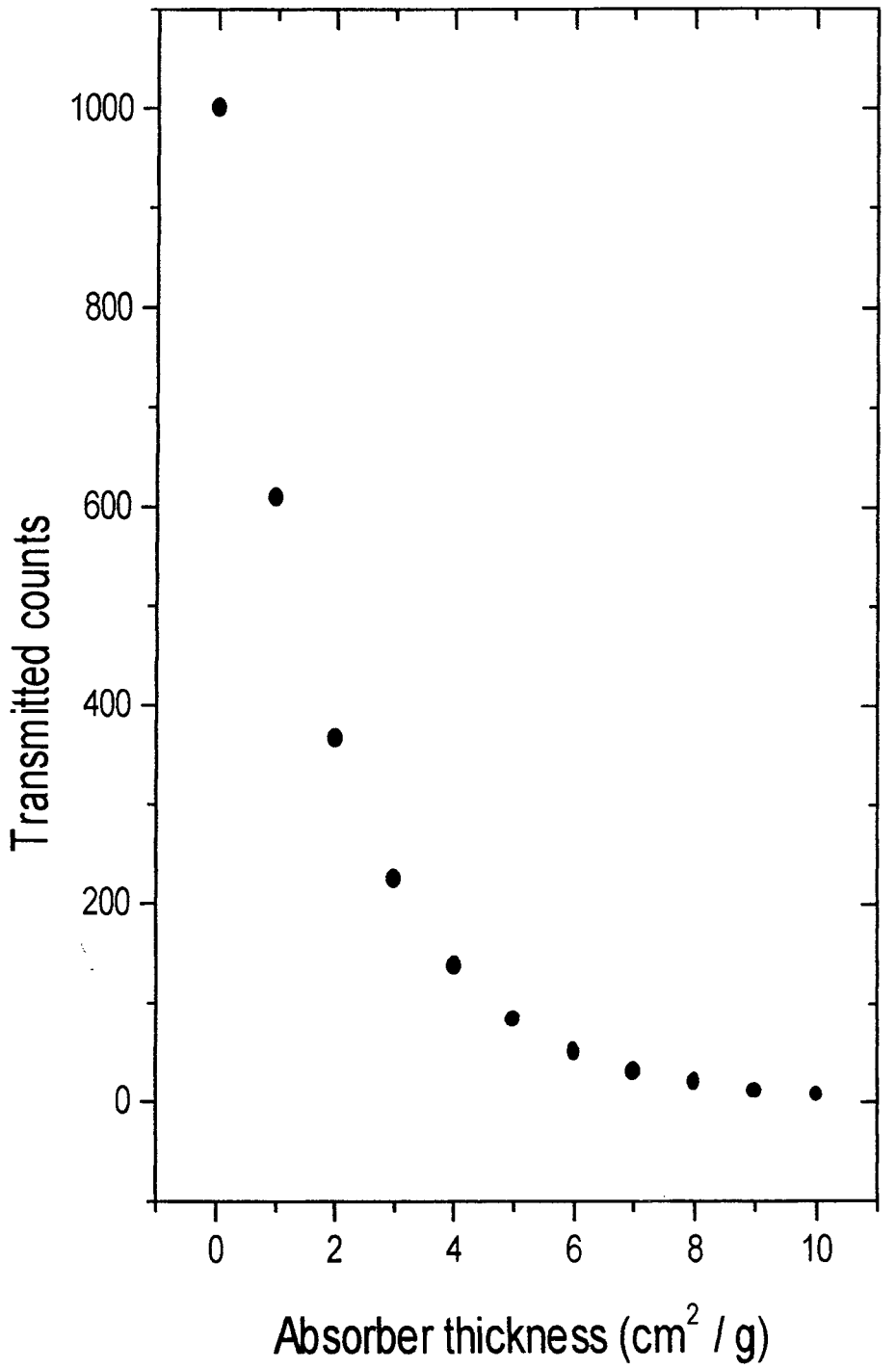

Fig 2.1 - Exponential variation of transmitted intensity vs. absorber thickness

Gamma rays with energies near 1MeV interact with the material mainly via three different processes. They are (1) Photoelectric effect, (2) Compton effect and (3) Pair production. Hence the attenuation coefficients can be written as

$$\mu_{tot} = \mu_{pe} + \mu_c + \mu_{pp} \quad \text{---------- (2.2)}$$

where μ_{pe} , μ_c , μ_{pp} are respectively the attenuation coefficients due to the photoelectric, Compton and Pair production processes. The contribution to μ_{tot} due to some other possible processes , such as Rayleigh scattering , gamma nuclear reactions and nuclear resonance absorption are very small compared to the contributions of the above mentioned three processes.

If the energy of the incident photon is greater than 1.02 MeV the pair production process is more significant. Rayleigh scattering is more relevant when the incident photon energy is low and for materials having high Z values.

2.2 Photoelectric Effect

When a gamma ray photon interacts with an atom via the photo electric effect, the whole amount of photon energy is absorbed by an electron of the atom which , consequently, is ejected with a finite kinetic energy.

$$E_e = E\gamma - B \quad \text{---------- (2.3)}$$

where Eγ is the energy of the incident photon and B is the binding energy of the electron in the atom. Fig 2.2 gives a schematic representation of the process. Usually photoelectric effect cannot take place from a free electron. This is because it is not possible to conserve

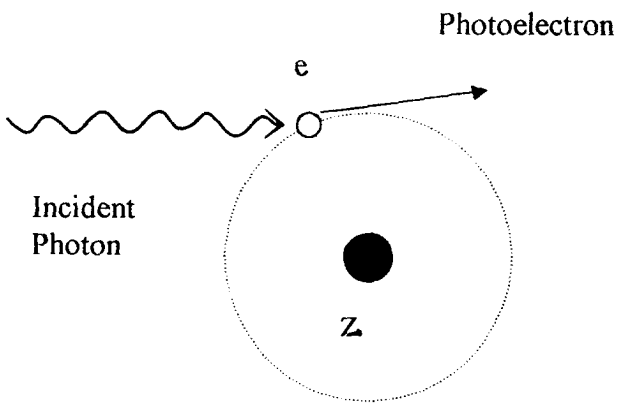

Fig 2.2. Schematic diagram of the Photo electric effect

both energy and momentum. About 80% of the absorption of gamma rays by photoelectric effect takes place in the K shell of the atom which has the largest binding energy. If the incident energy of the photon is less than the binding energy of K shell electrons, the photo electric absorption cannot take place from the K shell, but photoelectric absorption can still take place from the L,M or higher shells.

For energies less than 500 keV, the photoelectric absorption is more dominant for absorbers of high Z values. Also, the photoelectric absorption falls sharply as the photon energy decreases through K absorption edge. Similarly there will be sudden fall in absorption at L and M absorption edges also.

In the region a little above the absorption edge the cross section for photoelectric interaction of the gamma rays with the electron in the K shell of an atom with atomic number Z is given by Heitler [1] as

$$\sigma_k = 8/3\,[\pi r_o^2 Z^5 \alpha^4 2^{5/2}]\,(m_o c^2/E\gamma)^{7/2} \quad \text{---------- (2.4)}$$

where $r_o = e^2/m_o c^2$ is the classical radius of electron ,$\alpha = 2\pi e^2/hc$ is the fine structure constant and E_γ is the energy of the incident photon. The photoelectric cross section thus increases as Z^5 with the atomic number of the absorber and decreases as $(E_\gamma/m_o c^2)^{-7/2}$ with y – ray energy. In the region of the absorption edge , the cross section is multiplied by a factor f which is a function of $[B_k/(E_\gamma - B_k)]^{1/2}$.

When a gamma ray photon is absorbed by an electron in the K shell , it is ejected from the shell and leaves a vacancy in the K – shell. This vacancy will be compensated by the transfer of electron from the higher orbit (say L, M etc.). During this process characteristic X – rays will be produced.

There is some probability that instead of X – ray being emitted , the energy is imparted to one of the electrons in the higher shells or sub shells. The electron ejected in this way is called the Auger electron [2].

2.3 Pair production

If the energy of the gamma ray photon is greater than $2m_oc^2$ (1.02MeV), and the interaction takes place in the field of the nucleus, it may create an electron-positron pair. The nucleus, in whose field , the pair is formed, takes up the recoil momentum. At energies near the threshold, the pair formation takes place near the nucleus and the effect of the atomic electrons can be neglected Suppose the atom is not excited or ionized during the pair production, then such process is called elastic pair production. If the atomic electrons are also excited, then such a process is called an inelastic pair production. If the atom is ionized, the process is known as triplet pair production. Pair production can also take place in the field of an electron. The threshold for pair production in the electronic field is about $4m_oc^2$ (2.04MeV). At low gamma energy and large Z values for the absorbers, the cross section for pair production in the field of an electron is negligible compared to the pair production in the nuclear field. Bethe and Heitler [3] have calculated the cross- section for pair production and is given by the relation

$$\sigma_{pair} = Z^2 r_o^2 / 137 \, [28/9 \ln (2Et/moc^2) - 218/17] \quad \text{---------- (2.5)}$$

Jaegar [4] has given the following empirical formula for the pair production cross section for gamma ray energy of $3moc^2$.

$$\sigma_{pair} \times 10^{24} = 0.95\,(Z/137)^2 + 2.54(Z/137)^4 \quad \text{----------} \quad (2.6)$$

The pair production cross section increases with the atomic number of the absorber as Z^2. Near the threshold, the cross section increases rapidly with energy.

2.4 Elastic Scattering

In the case of elastic scattering, the internal energy of the atom remains a constant. Also, the energy of the incident photon is equal to the energy of the scattered photons, provided when the recoil energy of the electron is negligibly small. Usually the bound electrons and the nucleus contribute to the elastic scattering. If the scattering takes place from bound electron, then it is called the Rayleigh scattering. The contribution of nuclear scattering consists of nuclear Thompson scattering and nuclear resonance scattering. Thomson [5] assumed that the incident photon beam sets each quasi-free electron into forced resonant oscillations. Using non-relativistic electrodynamics, he calculated the cross sections for re-emission of electromagnetic radiation. In the case of nuclear resonance scattering, the nuclear level is excited by an incident photon and de-excited by the re-emission of the excitation energy. The cross-section is very small unless the gamma energy happens to be close one of the nucleus energy levels. A strong photon absorption is observed for many nuclei near gamma energies given by

$$E_\gamma = \varepsilon A^{-1/3} \quad \text{----------} \quad (2.7)$$

where ε varies between 70 MeV and 80 MeV and A is the atomic number of the element. The scattering corresponds to the Giant Dipole Resonance (GDR) scattering [6].

In the case of Rayleigh scattering [7], the photons are scattered by the bound electrons in a process where the atom is neither excited nor ionized. The scatterings from different parts of the atomic cloud combine to give coherent scattering. This process mainly occurs at low energies for large Z values where the electron binding energies influence the Compton effect. The differential scattering cross section is given by the relation

$$d\sigma / d\Omega = (r_o^2 / 2)(1 + \cos^2\theta)[F(x,z)]^2 \quad \text{----------} \quad (2.8)$$

where F(x,z) is called the atomic form factor, θ is scattering angle and x is the corresponding momentum transfer. The form factor values have been tabulated by Hubbel and Plechaty et al [8]. For small values of θ it approaches Z while for large values of θ it tends towards zero.

Delhbruck scattering [9] is due to virtual electron pair formation in the nuclear Coloumb field and is also called the elastic nuclear potential scattering. The cross section is very small.

Photodisintegration is possible if the γ ray energy exceeds the separation energy of a neutron or proton (>8MeV). The cross section is very small compared to that of photoelectric effect and pair production.

2.5 Inelastic scattering

Under certain circumstances, electrons can scatter photons independently. Such a process is called incoherent scattering or Compton scattering [10]. In this case some energy is scattered and some is transferred to kinetic energy. Compton process is almost independent of atomic number. It decreases with increase in energy. It is maximum around 1 MeV and is important between 0.5 MeV and 10 MeV. When a photon of energy E_γ strikes the perfectly free electron (at rest), the photon is scattered at angle θ with the direction of incident photon and the electron recoils at an angle ϕ. Fig 2.3 shows a schematic representation of this scattering process. Considering the process as elastic collision, Compton derived an expression for the energy of the scattered photon. The energy of the scattered photon at an angle θ is given by

$$E_\gamma' = E_\gamma / 1 + \alpha (1 - \cos\theta) \qquad \text{----------} \qquad (2.9)$$

where $\alpha = E/m_o c^2$. Compton scattering per electron is independent of Z because of the assumption of free electrons. Thus the scattering per atom is proportional to Z. The energy of the recoiling electron is given by the relation

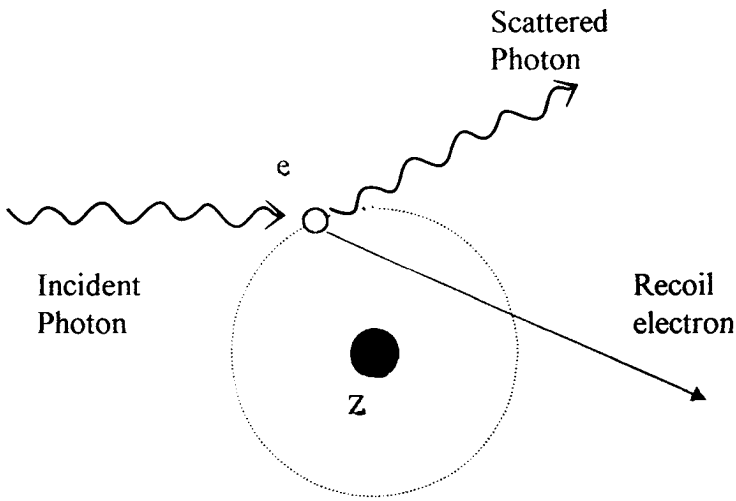

Fig 2.3. Schematic diagram of Compton scattering

$$T = E_\gamma \alpha (1-\cos\theta) / \{1 + \alpha (1-\cos\theta)\} \quad \text{---------- (2.10)}$$

The energy of the electron is maximum when the photon is scattered in the backward direction ($\theta = 180$). The maximum energy is

$$T_{max} = E_\gamma / (1 + 1/2\alpha) \quad \text{---------- (2.11)}$$

This maximum energy of the recoiling electron is known as the Compton edge.

Klein & Nishina [11] derived an expression for the Compton scattering of un polarized gamma rays. It is given by the relation:

$$d\sigma/d\Omega = (ro^2/2) \{1 + \alpha(1 - \cos\theta)\}^{-2} \times [\{1 + \cos^2\theta) + \alpha^2(1 - \cos\theta)^2 / \{1 + \alpha(1-\cos\theta)\}] \text{ --- (2.12)}$$

For every low energy photons ($\alpha \rightarrow 0$) the Compton scattering cross-section is the same as the Thomson scattering cross-section.

$$\sigma_o = (r_o^2 / 2) (1 + \cos^2\theta) \quad \text{---------- (2.13)}$$

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CHAPTER III

REVIEW OF PREVIOUS THEORETICAL AND EXPERIMENTAL STUDIES ON GAMMA RAY INTERACTIONS

3.1 Photo Electric Effect

The first theoretical calculation of the photoelectric effect was given by Hulme et al [1]. Hall [2] suggested a very well established theory in the year 1936. Heitler [3] obtained an expression for photoelectric absorption co-efficient for the K-shell. It is given by the following expression :

$$\sigma_K = (8/3)\ \pi r_o^2 Z^5 \alpha^4 2^{5/2} (m_o c^2/ E_\gamma)^{7/2} \qquad \text{----------(3.1)}$$

where $r_o = e^2 / m_o c^2$, the classical electron radius, $\alpha = 2\ \pi e^2 / he = 1/137$, the fine structure constant and E_γ is the energy of the incident photon. The photoelectric cross section is thus seen to increases as Z^5 with the atomic number of the absorber and to decreas as $(m_o c^2/ E_\gamma)^{7/2}$ with gamma ray energy. In the region of absorption edge B_k, the cross section is multiplied by a factor of $B_k / (E_\gamma - B_k)^{1/2}$. Detailed investigation has been carried out by Pratt et al [4]. The X-ray production cross section $\sigma_{L\alpha 1,2}$ for Li, Be, C, F and Si were determined experimentally by Malhi et al. [5]. They used Si(Li) detector to detect the X-rays. Goldstein [6] reported the dependence on both energy and Z of the ratio of total cross section of the K-shell. A brief summary of the theoretical and

experimental conclusions has been given by Pratt [7]. Gerward [8] measured the atomic photoelectric cross section of X-rays for Cu and Mo. Photoelectric absorption near the K-edge region in Xenon was measured by Deutsch and Brill[9]. With the help of a NaI (Tl) detector Rao et al. [10] measured the photoelectric cross-sections of Cu, W and Pb. K-edge photoelectric cross sections of some rare earth compounds have been measured by Lingam et al [11]. Jahagirdar et al. [12] used a NaI (Tl) detector to investigate the photoelectric cross sections of the oxides of five rare earth elements at energies 123.6 keV and 145.4 keV. Accurate measurements of K_α radiation emission cross section were carried out on thick foils of Gd and Dy using 59.54 keV photon by Bradley et al. [13]. Direct measurements of photoelectric cross sections to observe the photo electrons was reported by Titus [14]. Rajendra Prasad et al. [15] measured the photoelectric cross section of Cd and In with the help of Si(Li) detector using ^{241}Am source. Photoelectric cross section of various alloys have been determined by Siddappa et al. [16] by using scintillation spectrometers. By using coincidence technique, Ranganathaiah et al. [17] measured the K-shell photoelectric cross section in various targets such as Sn, Au etc.

K-X-ray intensity ratios in the alloy of tin & nickel and chromium & nickel have been measured for different compositions using 59.54 keV gamma ray fluorescence by Bhuinya [18] et al. L-shell X-ray production cross sections have been measured for Li, Be, C, Yb etc. by Malhi et al. [19].

3.2. Pair Production

On the basis of Dirac theory, the creation of positron-electron pair can be explained. Bethe and Heitler [20] have calculated the cross-section for pair production neglecting the screening effect under the assumption that there is no interaction between the nucleus and the created electron and positron. In the process, no net electric charge is created since the positron and the electron carry opposite charges. If the photon has energy in excess of 1.02MeV, this excess energy would be shared between the positron and the electron. Thus,

$$h\nu - 1.022 = E_+ + E_- \qquad \text{----------(3.2)}$$

where E_+ and E_- are the kinetic energies of the positron and the electron respectively. Bethe and Maximon [21] studied the variation of pair production cross section with Z for various elements having low Z values. Wheeler and Lamb [22] considered the pair production in the field of atomic electrons. Theoretical calculations for pair production cross sections for various energies have been made by Mark and Olsen [23].

3.3. Elastic scattering

In the case of elastic scattering, the scattered photon will have almost same energy as the incident photon except for a negligible difference due to the recoil energy loss. Both the nucleus and the electron will contribute to the elastic scattering. G.M. counters were used to measure the scattering cross section in the earliest experiments. With the advent of modern computers and higher resolution detectors, the accuracy of the

measurements of scattering cross sections improved a lot.

Differential coherent scattering cross sections have been experimentally determined for the photon energies 26.4 and 59.54 keV, using ^{241}Am source by Chong et al. [24]. The measurements were performed using a standard back-scattering geometry set up to obtain scattering angles of 145° and 165°. The targets used were Mo, Nb and Zr foils.

Kane et al. [25] predicted the γ ray elastic scattering cross section close to K-shell thresholds of high Z elements by means of S-matrix treatment. Coherent and Compton scattering cross-section for the elements such as Mg, Al, Ag etc. have been measured at 33.29 keV X-ray energy by Rao et al. [26]. Measurements have been carried out using an X-ray tube with a secondary exciter system as the excitation source instead of radioisotopes. Experimental coherent scattering cross sections are compared with the theoretical values.

Bradley et al. [27] measured the differential coherent scattering cross-sections of 279 and 662 keV γ ray photons for Cu, Sn and Pb. A critical dependence of photon attenuation upon transverse target thickness, demanding target thickness considerably less than one mean free path, is confirmed.

Whole-atom differential coherent scattering cross sections were measured for 59.54 keV gamma rays scattered at 90° by Cu, Ag, Cd, Gd, Dy etc. employing a reflection geometry set up and an effective graded shielding arrangement by Nayak et al. [28]. They

used a 2 cm^3 hyper pure Ge detector for detecting coherently scattered gamma rays. After that the measured cross sections were compared with the theoretical values based on the numerical partial wave calculations for the available cases. Differential cross sections for Rayleigh scattering of 59.54 keV photons from Sn, Mo, Ta, Cd etc. were measured for angles ranging from 60 to 165° by Nandi et al. [29] with the help of an intrinsic Germanium detector. Basavaraju et al. [30] used a high purity Germanium detector to determine differential cross section for the elastic scattering of 81 keV gamma rays by aluminium, nickel, tantalum, gold etc. through angles 60°, 90°, 120° and 133°. They also calculated the Rayleigh scattering amplitudes for the above mentioned metals. Baumann et al. [31] measured the Delbruck scattering cross section of lead in the energy range 0.025 MeV to 0.1 MeV.

Experimental support for the anomalous dispersion effects of the rare earth elements, especially for Z = 70 were given by Bui et al. [32] by using 59.54 keV gamma rays.

3.4. Inelastic Scattering

Klein and Nishina [33] considered the Compton scattering as a collision between photon and a free electron. They obtained an expression for calculating the cross section with the help of Dirac equation. The formula obtained by them for the un polarized radiation is called the Klein-Nishina formula. Later this formula was discussed by Evans [34]. Theoretical calculations on Compton Scattering were first done by Bewilogua [35]

starting from the equation derived by Heisenberg [36]. The incoherent Scattering cross-section of the photon is given by the relation

$$d\sigma / d\,\Omega_{incoh} = d\sigma/d\,\Omega\ S\,(q,z) \qquad \text{----------} \qquad (3.3)$$

Where S(q,z) is the incoherent scattering function and $d\sigma/d\Omega$ is the scattering cross section for the free electron. If relativistic effects are considered, then the Klein Nishina cross section can be expressed as

$$d\sigma/d\Omega = (ro^2/2)\,\{1 + \alpha(1 - \cos\theta)\}^{-2} \times$$

$$[\{1 + \cos^2\theta) + \alpha^2(1 - \cos\theta)^2 / \{\,1 + \alpha(1-\cos\theta)\,\}\,] \text{---} \quad (3.4)$$

Incoherent scattering functions were determined experimentally for 662 keV gamma rays by Rao et al. [37] at two scattering angles 30° and 40°. They used a high resolution HPGe detector. The targets used were Au, U, Yb. Ag. Incoherent Scattering functions have been experimentally determined for 84.4 and 123.6 keV photons in the angular range 30° – 110° for the elements Sc, Y, La, Dy and Pb. Compton Scattering cross sections of Al, Fe, Au and Pb samples at 90 were determined by Namito et al with the help of HPGe detector. They used a 2-5 GeV synchrotron radiation facility. Compton scattering cross sections for the elements Mg, Cu, Y, Mo, Pb, Ag etc. have been measured at 32.06 keV X-ray energies. Measurements have been performed using an X-ray tube with a secondary exciter system as the excitation source instead of radioisotopes. They found that experimental incoherent scattering cross sections are higher than the theoretical estimates for low medium Z elements and lower for heavy elements. The latter

is due to the effect of electron binding at low photon energies for heavy elements.

Pinto [39] et al. determined experimentally that the whole atom differential incoherent scattering cross sections for 279.2 keV gamma rays in Cu, Mo, Ag, Dy, Ho etc. at 90° scattering using a high resolution HPGe detector. Incoherent scattering functions were extracted from the measured scattering cross sections at momentum transfer of 15.92 A^{o-1}. Shivaramu et al. [40] measured the differential scattering cross section of 279 and 322 keV photons in copper, tin and lead experimentally at different angles ranging from 10° -120° . The cross sections of 662 keV and 1115 keV photons were also determined in Cu, Sb and Pb using a cone geometry between 3° and 8°. The incoherent scattering functions derived from the experimental results were compared with the values calculated by Cromer on the basis of Hartree-Fock wave functions. Differential incoherent scattering cross sections for 279, 662 and 843 keV photons in lead, tin and copper at three scattering angles 20,30 and 40° have been measured by Bose et al. [41]. A photon Counter with a uniform spectral sensitivity was used for the detection of the scattered photons. The scattering geometry used in this experiment was also a special type, namely the surface of revolution which has several advantages over the conventional ring geometry.

Measurements on Compton line shapes for scattering have been reported by Dow et al. [42]. They used various sources having gamma energies between 779 and 1408 keV at different scattering angles 5, 7, 10 and 15°. The targets used were Al, Sn, Ta and Pb. Shivananda et al. [43] have applied the mixture rule to derive the incoherent scattering

functions for several elements from the measured scattering cross sections of the corresponding compounds. Compton scattering cross sections of several elements at scattering angles from 5 to 25° has been measured by Gaspar et al. [44] for the energy 145 keV.

3.5 Photon Attenuation studies

Gamma ray attenuation measurements were carried by the help of G M Counters by the researches for their earlier works. In the X-ray regions proportional counters were used. With the advent of modern detectors such as scintillation and semi conductor detectors, the accuracy of the results have improved a lot. Reviews on detailed investigations on gamma ray attenuation have been given by Davison and Evans [45]. They studied the details of the absorption of radiation in the energy range 0.1 MeV to 6 MeV. In 1970 Storm and Israel [46] had done a wonderful job to compile the attenuation coefficients of elements for various energies. Photon cross sections of all elements have been compiled and arranged in a table by Hubbel et al. [47] in the year 1980. They also listed photoelectric and pair production cross sections, coherent and incoherent scattering cross sections. Hubbel [48] tabulated the theoretical values of attenuation coefficients of 40 elements of Z values from 1 to 92. Theoretical values of attenuation coefficients of elements were tabulated by Henke et al. [49]. McMaster [50] suggested an interpolation formula to calculate the attenuation coefficients in the energy range 1 keV to 1000 keV. Analytical fits for the measurement of attenuation coefficients have been suggested by Hsu et al. [51] for the purpose of interpolation. Recent world wide interest in

computerized tomography has led Kouris et al. [52] to carry out a reappraisal by calculation of the method of elemental analysis based on the measurement of the change in the photon mass attenuation coefficient of an element, a compound or a mixture when an impurity is introduced into the mixture. Values have been calculated of the minimum detectable fraction for each element ($I < Z < 92$), which would change the mass attenuation co-efficient of water by 1% at energies ranging from 1 keV to 1 MeV.

Bradley et al. [53] have measured the attenuation coefficients of tropical hardwood samples. They used an ^{241}Am source and a NaI detector. Teli et al. [54] measured the mass attenuation coefficients of dilute solutions of sodium chloride using 662 keV gamma rays.

X-ray absorption coefficient of Rubidium in the K-edge region was investigated by Preseren et al. [56] with the help of synchrotron light. Photon cross sections near the X-ray absorption edges of Ti, Ni, Pt and Au were very accurately measured by Parthasaradhi et al. [57] by using synchrotron radiation.

Careful measurements of the attenuation coefficients reveals important information about the composition of tissues [58]. Effective atomic numbers for photon energy absorption of some low Z substances of dosimetric interest were investigated by Shivaramu et al. [59] using an HPGe detector. Effective atomic numbers for W/Cu alloys were determined very accurately by using transmission experiments with the help of HPGe detector by Marty et al [60]. Total photon attenuation cross sections of helium

for photons in the energy range of 3-14 keV have been measured by Azuma [61] et al. They found that photo ionization cross section is rapidly decreasing at these energies, so that the Compton Scattering is significant at 4 keV and dominates at higher energies. Kumar [62] et al. calculated theoretical values of effective atomic numbers (Z_{eff}) of different clay minerals for total photon interaction in the energy region 10 keV to 10 MeV.

The linear and mass attenuation coefficients of different types of soil, sand, building materials and heavy beach mineral samples from the Chittagong and Cox's Bazar area of Bangladesh were measured using a high resolution HPGe detector by Alam et al. [63]. They used three different sources such as ^{133}Ba, ^{137}Cs, ^{60}Co. Investigations of X-ray and gamma ray attenuation in solutions has been carried out by Gerward [64] . The rule of mixture for the calculation of mass and linear attenuation coefficients is elaborated in the general case as well as in the limit of extreme dilution. In studies conducted by Mahmoud et al. [65], the attenuation and scattering coefficients of gamma rays in the natural rocks silstone and conglomerate and in compressed powderal silstone have been measured. The effects of the particle size (grain diameter d) and sample density with radiation energy were investigated. Flux distributions inside the absorber were studied by the method of isoflux curves. Their results showed an inverse proportionality between μ and both d and I. The side scattering co-efficient (ϕ) is found to be directly proportional to both d and I. They had also seen that the density ρ is proportional to ϕ.

Precise measurements of the X-ray attenuation coefficient of crystalline silicon have been made in the energy range 25 to 50 keV by Mika et al [66].

Alejandro and Rand [67] measured the X-ray absorption jump ratio of erbium with the help of high resolution intrinsic germanium detector by attenuation, with an erbium foil, of a Compton peak produced by the scattering of 60 keV X-rays. Sherman and Ewart [68] have also conducted experiments to measure total photon absorption co-efficient cross sections and pair production cross sections from them. From total attenuation measurements Roy [69] estimated incoherent scattering cross section. He comments on the use of the relativistic form factor to estimate the contribution of coherent scattering of photons. Kumar et al. [70] measured the attenuation coefficients of aqueous solutions of alkali metal chlorides viz LiCl, NaCl and KCl, having different concentrations. They had various sources having gamma rays in the range 80 to 1400 keV. The experimental results are analyzed in terms of total cross sections, effective atomic numbers and electron density values of the solution. In addition to that, molar extinction coefficients, interaction cross sections and interaction radii for the solid solutes in aqueous solutions have also been calculated at these energies and concentrations. The mixture rule is applied to examine the compatibility of the results.

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STUDIES ON GAMMA ATTENUATION AND PHOTOELECTRIC EFFECT USING ^{241}Am GAMMA RAYS

Thesis submitted to the University of Calicut

In partial fulfillment of the requirements

for the Degree of

DOCTOR OF PHILOSOPHY

IN PHYSICS

By

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2003

CHAPTER IV

EXPERIMENTAL STUDIES ON GAMMA RAY ATTENUATION COEFFICIENTS FOR SOME RARE EARTH ELEMENTS

4.1 Introduction

Knowledge of the various processes of interaction of gamma rays with matter is of utmost importance in may practical situations like gamma ray shielding problems, gamma ray transport problems etc. The total cross section for the interaction of gamma rays is conventionally evaluated by measuring the attenuation of the gamma rays through suitable absorbers using the so-called narrow beam good geometry set up [1]. Here, the in scattering of the gamma rays from the absorber into the detector is suitably minimized. Wherever possible, the absorbers will be in the form of thin sheets of the elements. However, when pure elemental absorbers are not available, compounds of the elements are also used. In such cases, the absorbers are either in the form of pellets or as aqueous solutions. In the latter cases, use is made of the mixture rule [2].

On the theoretical side, various compilations of gamma ray attenuation coefficients as functions of the gamma energy are available in the literature [3 - 5]. The total attenuation coefficient is calculated as the sum of the contributions from the three individual processes of gamma ray interaction, viz; photoelectric effect, scattering and pair production. The overall accuracy of these compilations depend on the accuracy of

the calculations of the individual processes and depends on the gamma energy. Especially, when the gamma energy is near to a K-edge energy, the photoelectric cross sections are not precisely known and this error will be reflected in the corresponding attenuation coefficients also. Experimental measurements of the attenuation coefficients near the K-edges are thus very important.

^{241}Am presents a very suitable gamma ray source for measurements around the K-edge region. Its gamma energy, 59.54 keV, lies in between the K-edges of the rare earth elements Thulium (59.39 keV) and Ytterbium (61.332 keV). Keeping this fact in mind, we have chosen ^{241}Am source for the present gamma ray measurements on several rare earth elements from Ce (Z=58) to Yb (Z=70). In the following sections, we describe the details of the experimental set up and method and the results obtained.

4.2 Principle of Experimental method

When gamma rays are passed through matter, their intensity will be attenuated according to the exponential law

$$I = I_o e^{-\mu x} \qquad \text{----------} (4.1)$$

where μ is the linear attenuation coefficient and x is the thickness of the target. For a mixture or a compound , we can apply the mixture rule. The mass attenuation coefficient for a mixture is given by the relation

$$\mu/\rho = \Sigma_i f_i \mu_i'/\rho_i \qquad \text{----------} (4.2)$$

where f_i is the weight fraction of the i^{th} element ρ_i is the density of the i^{th} element and μ_i' is the linear attenuation coefficient of i^{th} element.

4.3 Details of the Experimental Set up

The experimental arrangement used in the present investigations is shown in fig. 4.1. For this purpose, a fine narrow beam geometry is used. The detector is well shielded with the help of lead blocks. The in-scattering angle is kept to a reasonably small value.

4.3.1 The source

A disk source of ^{241}Am obtained from BARC, Mumbai was used for the present experimental study. It had a strength of 2.4 μCi. It was placed at a distance of about 20 cm from the detector as in the figure 4.1. ^{241}Am decays to ^{237}Np by emitting alpha particles. Apart from the emission of gamma rays of energy 59.54 keV, 33.20 keV and 26.36 keV, the source also emits Np L- X-ray lines . The decay scheme is shown in fig. 4.2.

4.3.2 Absorbers

The absorbers used were prepared using oxides of ten rare earth elements. They are : Pr, Dy, Er, Gd, Eu, Lu, Tm, Nd, Tb, Er and Yb. The purity of the materials was better than 99 %. Two sets of targets have been prepared for each compound.

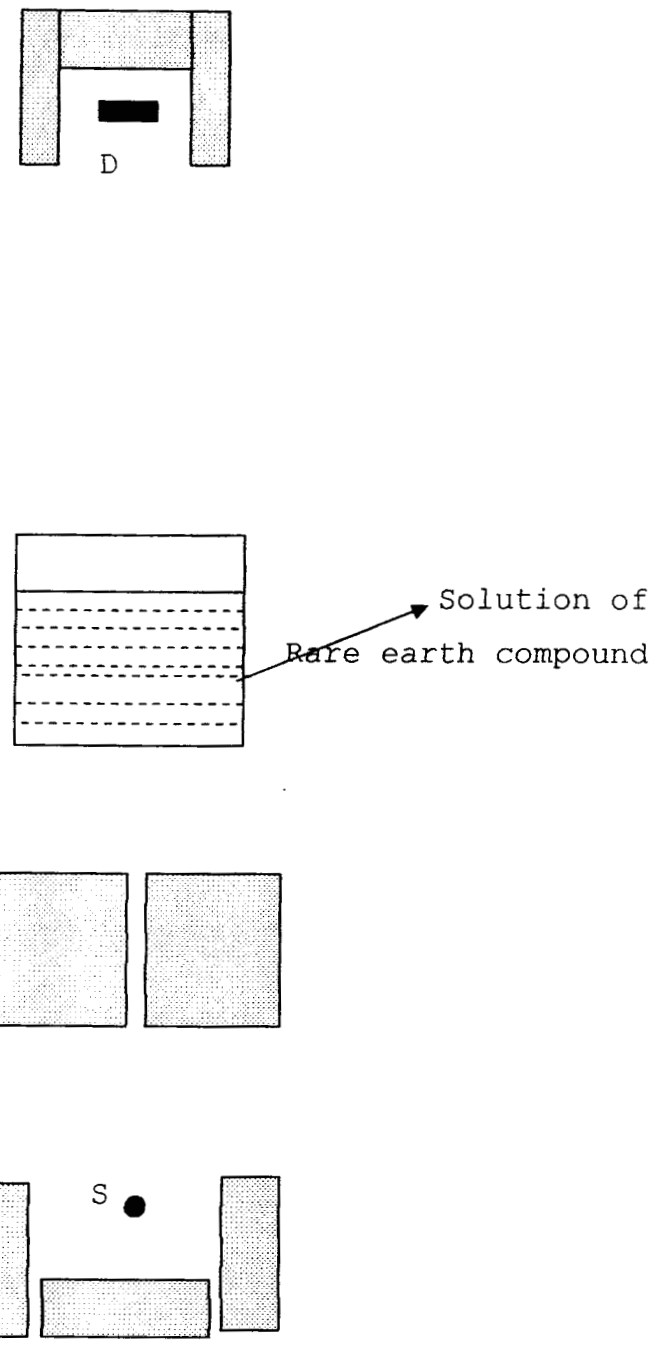

Fig. 4.1. Vertical narrow beam geometry set up

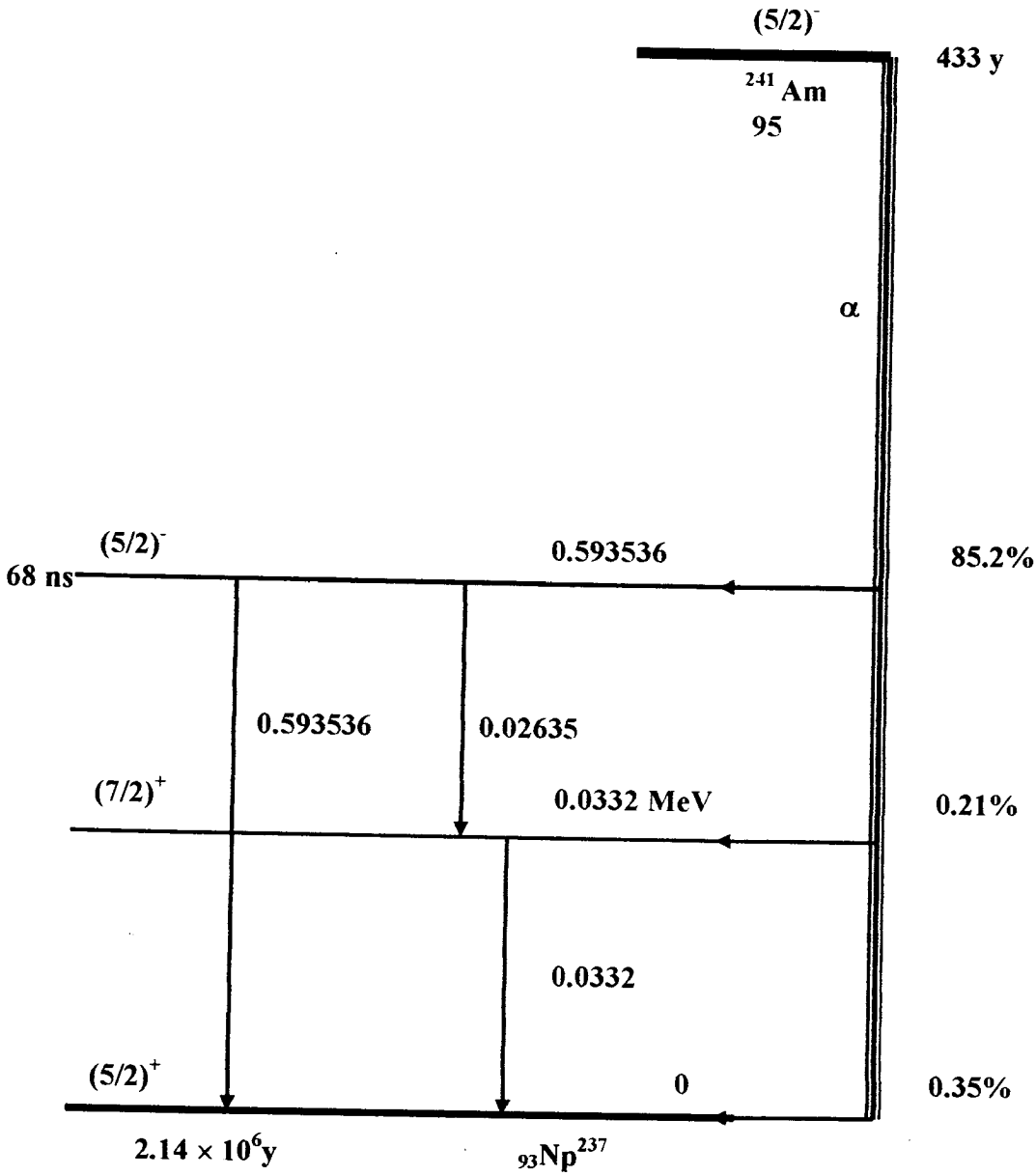

Fig 4.2 Decay scheme of ^{241}Am

4.3.2.1 Pellet absorbers

500 mg of the respective oxide was mixed with 1 gm of KBr as binding agent. After thoroughly mixing the two compounds, the mixture is ground well with the help of a mortar and pestle. Thereafter, the mixture was divided into five equal parts. A pelletizer was used for preparing the pellet absorbers. A pressure of about ten tones is applied. The diameter of the pellets is about 1.2 cm.

4.3.2.2. Dilute aqueous solution absorbers

Usually oxides of rare earth elements are not soluble in water. Consequently, conc. Nitric acid (Analar Reagent Grade) has been used to make the respective solutions. Twenty milli litres of conc.HNO_3 is added to 500 mg of rare earth oxides . Most of the oxides dissolve in HNO_3 but some oxides such as those of Gd and Tb which are not soluble in the acid directly, were heated to 60° C. Thereafter the excess acid and water were allowed to evaporate completely. The ensuing chemical reaction is as follows

$$Gd_2O_3 + 6\,HNO_3 \rightarrow 2\,Gd(NO_3)_3 + 3\,H_2O \qquad \text{---------- (4.3)}$$

Then 20 ml of pure distilled water is poured into the residue and stirred well to get the gadolinium nitrate solution and also terbium nitrate solution. These nitrate solutions were also prepared in various concentrations. The solution is taken in a small beaker and kept at a convenient distance from the detector in the narrow beam good geometry set up

for the measurement of attenuation coefficients. The levels of the solution absorbers were measured using a sensitive traveling microscope.

4.3.3. Detector and Electronics

A 2" x 1 ¾ " NaI (Tl) detector, supplied by Nucleonix, Hyderabad was used in the measurements. The detector output pulses were amplified by a 571 ORTEC amplifier. The spectrum of gamma rays transmitted through the absorber was collected with the help of a CAMAC based Multichannel analyzer. The software used for this purpose was "FREEDOM" [6], obtained from Nuclear Science Centre, New Delhi.

4.3.4. Data Collection and Analysis

In the case of the pellet absorbers, the absorber thickness was varied by adding more pellets. For the aqueous solutions, the height of the solutions in the beaker is varied by adding more and more drops of the liquid. For each absorber thickness, transmitted gamma spectrum was collected for sufficient time periods (typically ten minutes) to ensure reasonable statistical accuracy. The background spectra were also collected in between these runs. Net absorption spectra were obtained by subtracting the background. A typical spectrum obtained for the transmitted gamma rays for the energy 59.54 keV is shown in figure 4.3. For various thicknesses of the absorbers, the area under the photo peak of the transmitted spectrum was extracted and taken as a measure of the transmitted counts. The logarithms of the counts were plotted against the absorber

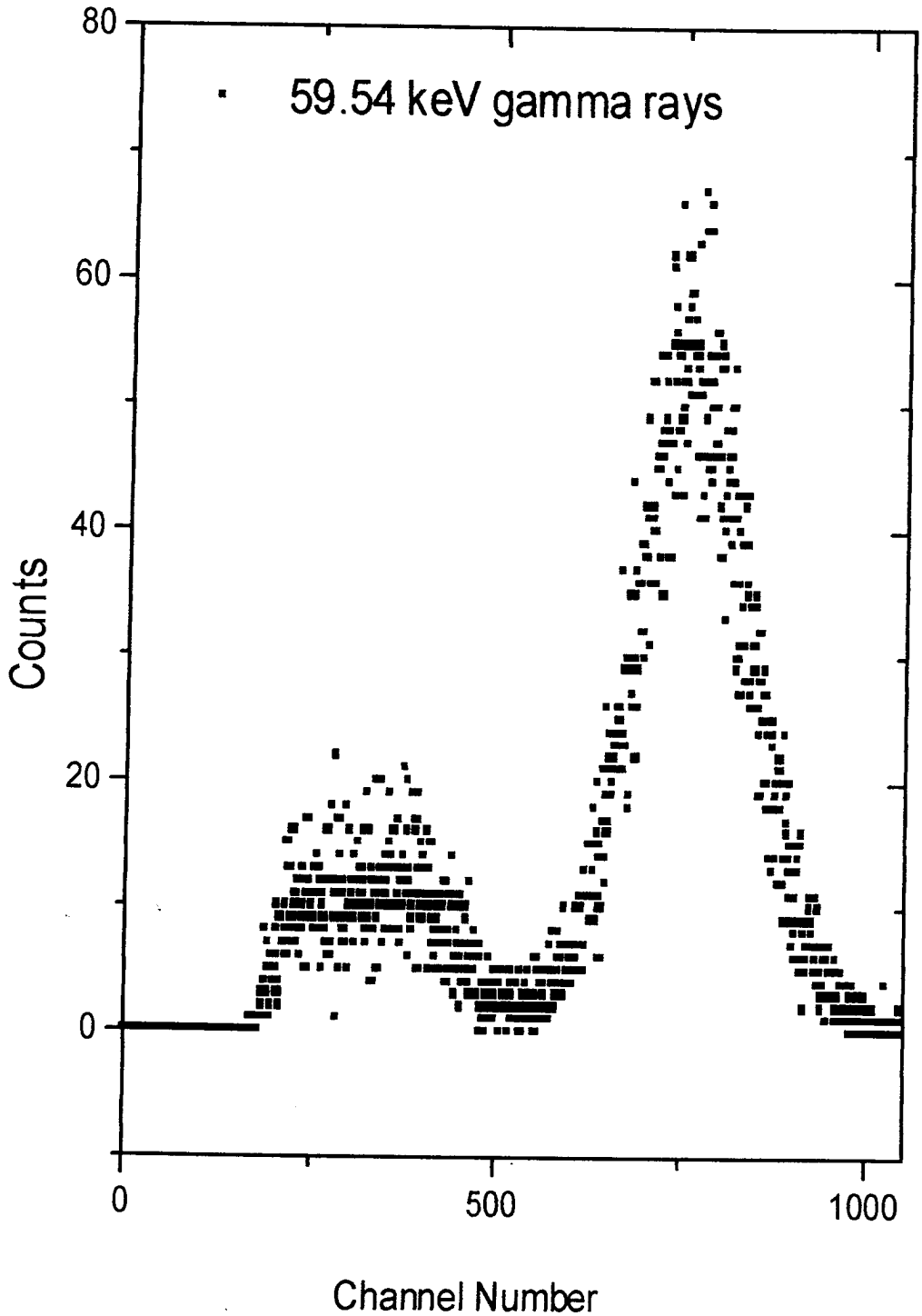

Fig 4.3-Typical spectrum of 59.54 keV gamma rays transmitted through aqueous solution of rare earth oxide

thickness, obtaining a linear plot. From the slope of the straight line, the attenuation coefficient was calculated in units of cm^2 /gm. For this purpose the densities of the absorbers were determined separately. The experiment was repeated for various concentrations of the rare earth compounds.

The attenuation coefficients measured as above correspond to the mixtures of the rare earth oxides (or the nitrates as the case may be) with water in the case of aqueous solutions and with Potassium Bromide in the case of the pellet absorbers. In order to extract the attenuation coefficients of the rare earth elements, it is first necessary to know the coefficients for KBr and water. The values of the attenuation coefficients were separately measured for water and for KBr by using pure water and aqueous solution of KBr. Also, the coefficient for KBr was measured using pure KBr pellets. Using these additional data, the mixture rule (equation 4.2) was used to extract the attenuation coefficients of the rare earth oxides (or nitrates). Again, using theoretical values of the coefficients for oxygen and nitrogen, available from the XCOM package [5], those for the rare earth elements have been extracted. We also measured the attenuation coefficients for tantalum and lead, using thin foils of these elements.

In order to find out the effect of the compactness of the pellet on the measured attenuation coefficients, we prepared the pellets using pressures of 7 , 8, 9, 10, 12 and 15 tonnes. The maximum variation in μ was only about 5 %.

4.4 RESULTS

A typical plot of the variation of attenuation coefficients as a function of concentration is plotted in figure 4.4 for Pr_2O_3 and Gd_2O_3 solutions. It is seen that the plots are a straight lines as expected from the mixture rule.

The values of the attenuation coefficients for pure water and KBr , determined in the separate studies as mentioned in the previous section, are given in Table 4.1 and compared with XCOM values. It is seen that the agreement is reasonably good.

Table 4.1 – Attenuation coefficients for water and KBr compared with XCOM values

Compound		Attenuation coefficients (cm^2 / g)	
		Present experiment	**XCOM values**
Water			0.2066
KBr	Using aqueous solution	1.92 ± 0.10	1.96
	Using pellet absorbers	2.00 ± 0.13	

The values of the attenuation coefficients, obtained from the present investigations, for the various rare earth elements are given in table 4.2. The table gives the experimental values of the coefficients, obtained from the data on aqueous solutions as well as the pellets. The experimental errors are estimated to be around 10 %. These values are also compared with the theoretical values derived using the XCOM package. Fig 4.5 gives the results in graphical form. It is seen that the agreement with the XCOM

values is reasonable, taking into account the errors involved. Moreover, the sudden fall in the attenuation coefficient near Z= 70 (Yb) is worth noticing. This corresponds to the fact that the gamma energy (59.54 keV) is in between the K_edge energies of Thulium (Z = 69) and Ytterbium (Z = 70).

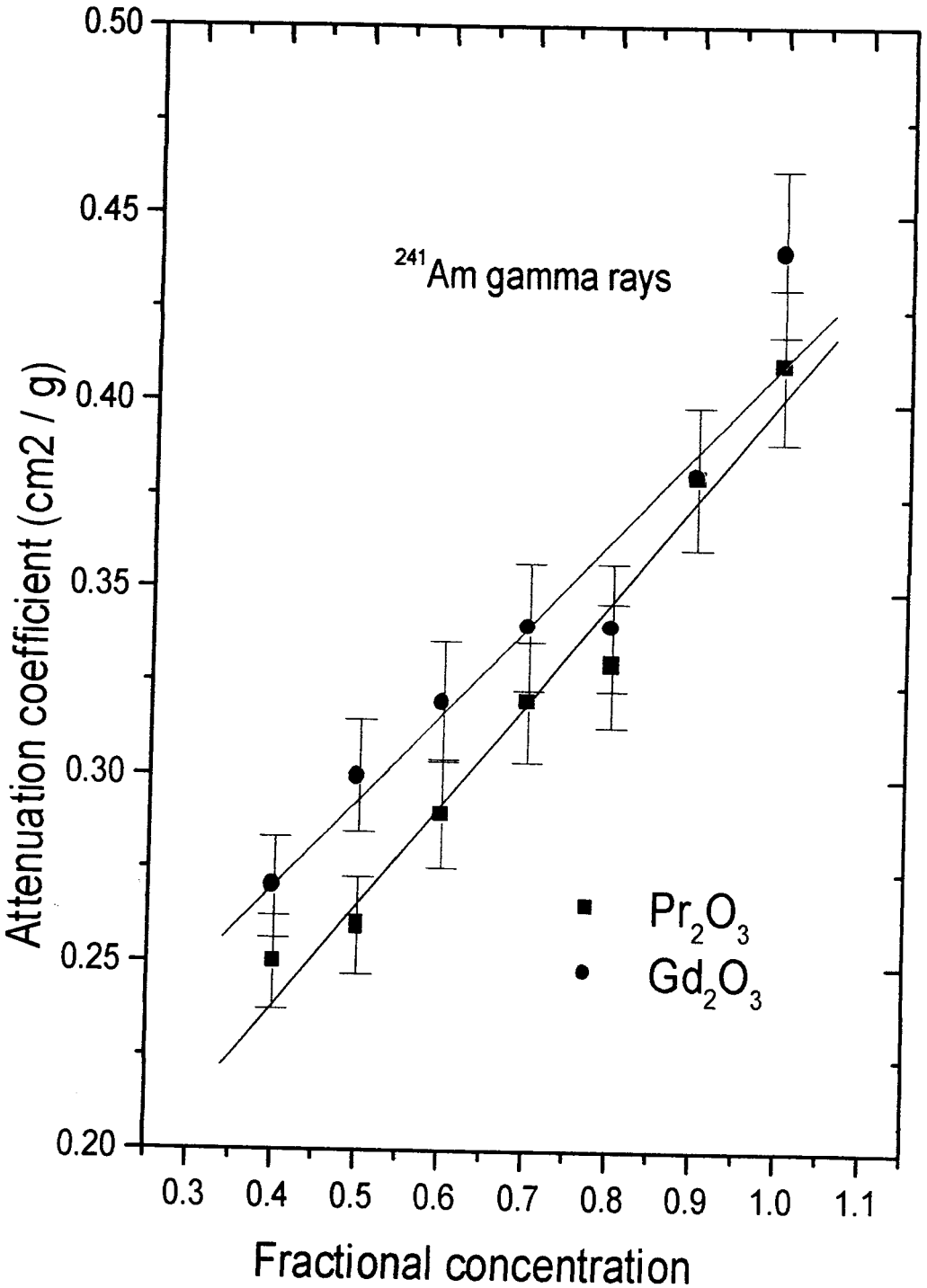

Fig 4.4 - Variation of attenuation coefficient as a function of concentration

TABLE 4.2 – Comparison of experimental attenuation coefficients with XCOM values for rare earth elements at 59.54 keV

Atomic number	Element	Mass attenuation Coefficient (cm^2 /gm)		
		Present Experiment		XCOM Values
		Using Aqueous solution	Using Pellets	
58	Ce	-	9.3 ± 1.0	9.6
59	Pr	12.1 ± 1.2	10.7 ± 1.2	11.1
60	Nd	10.2 ± 1.1	9.5 ± 1.1	11.1
62	Sm	12.2 ± 1.3	10.9 ± 1.2	11.3
63	Eu	10.3 ± 1.1	12.3 ± 1.3	11.8
64	Gd	11.2 ± 1.2	13.3 ± 1.4	12.0
65	Tb	10.8 ± 1.2	12.0 ± 1.3	12.5
66	Dy	10.2 ± 1.2	11.9 ± 1.3	12.8
68	Er		13.1 ± 1.5	13.9
70	Yb	3.3 ± 0.4	3.0 ± 0.4	3.2
71	Lu	-	4.0 ± 0.4	3.6
73	Ta	-	4.0 ± 0.4	3.6
82	Pb	-	5.9 ± 0.7	5.0

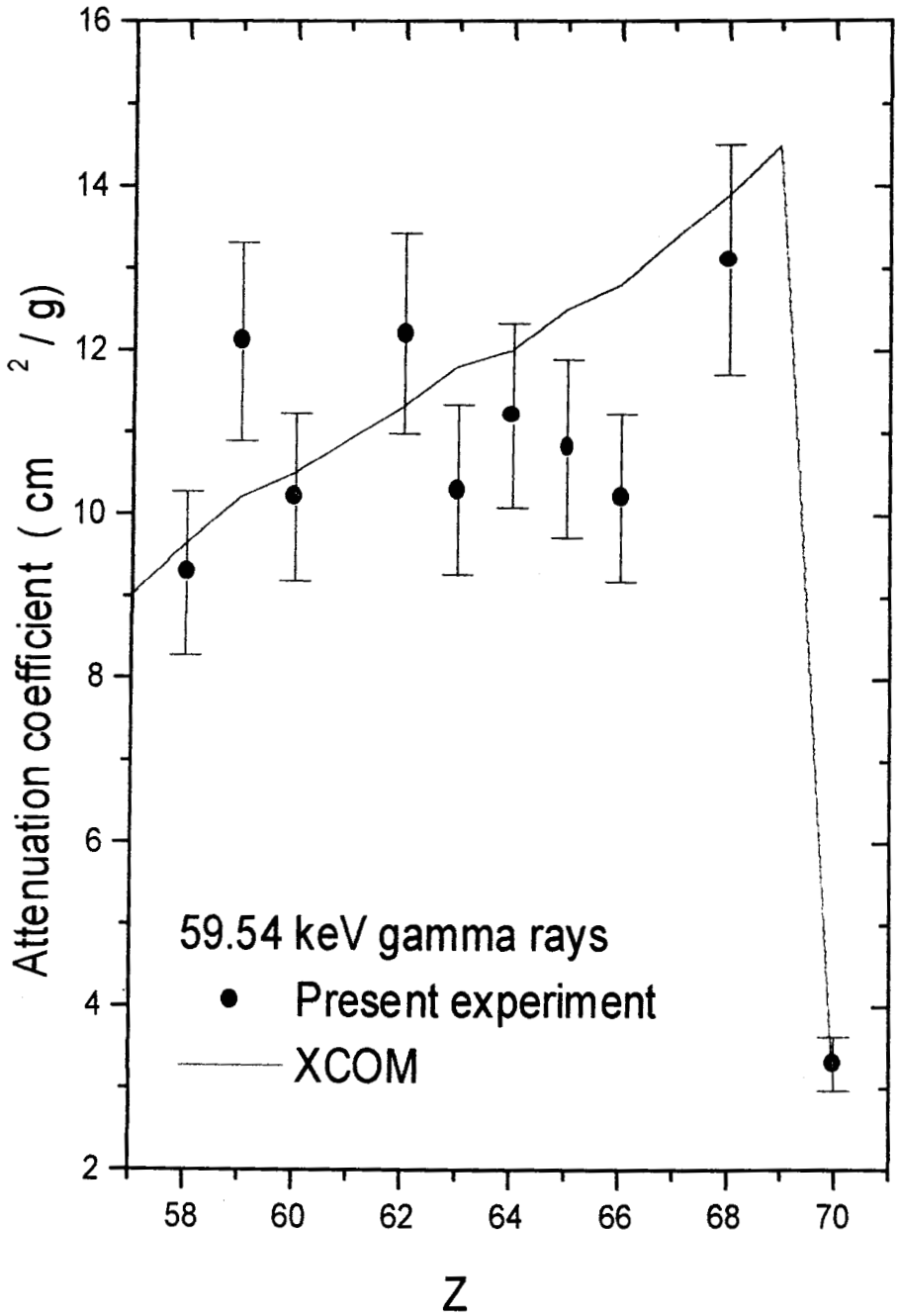

Fig 4.5 Variation of attenuation coefficient as a function of atomic number for rare earth elements

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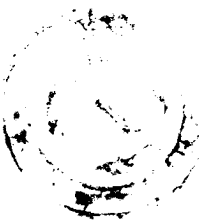
CHAPTER V

PHOTOELECTRIC STUDIES ON RARE EARTH COMPOUNDS



5.1 Principle of the experimental method

Suppose S is the number of photons emitted in unit time by a source. Let N be the number of atoms per unit area of the target and let it subtend a solid angle Ω_t at the center of the source. The number of X - ray photons emitted per unit solid angle at an angle θ to the incident beam is given by

$$I = S / 4\pi \Omega_\tau N d\sigma(\theta) / d\Omega \quad \text{---------- (5.1)}$$

where $d\sigma(\theta) / d\Omega$ is the differential cross section for the photoelectric effect and S is the number of gamma rays emitted per second by the source. If T is the effective transmission of the target and Ω_D is the solid angle subtended by the detector at the target; then the number of photons that will fall on the detector is equal to $T\Omega_D I$. Out of these photons, only a small fraction η of photons will be detected by the counting system, where η is the efficiency of the detector at the gamma energy used. From the observed X – ray spectrum, the K – X ray intensity will be given by the following relation :

$$N_i = S \Omega_t N_o(\rho t/A) (\sigma_K/4\pi) T_a T_d \Omega_D \eta \, d\sigma/d\Omega \quad \text{---------- (5.2)}$$

Here, N_o is the Avogadro number and ρ is the density of the target. T_a is the attenuation correction for the target and T_d is the attenuation correction for the detector covering.

The effective transmission factor corresponding to the i^{th} element, T_i can be shown to be given by

$$T_i = \{1 - \exp [- t (\mu \sec \gamma_i + \mu' \sec \gamma_i')]\} / t (\mu \sec \gamma_i + \mu' \sec \gamma_i') \quad \text{--------} \quad (5.3)$$

where μ is the mass attenuation co-efficient of the target for the incident gamma rays; μ' is the mass attenuation coefficient for the scattered gamma rays; t is the thickness of the target; γ_i is the angle made by the incident gamma rays with the normal to the target plane and γ_i' is the angle made by the scattered gamma rays with the normal to the target plane at the position of the ith element. The presence of KBr in the pellet affects only the factor T_a.

We have adopted the following method to eliminate the unknown factor S in the expression 5.2. The source is kept directly in the front of the detector at the target position. The detected gamma counts is given by

$$N_s = (S / 4\pi)\ \Omega_d\ \eta' \quad \text{----------} \quad (5.4)$$

Now, dividing equation 5.3 by 5.4 we get an expression for σ_K. The ratio η' / η of the detector efficiencies is practically equal to unity, since the detector thickness is comparatively large.

5.2 Details of the Experimental Setup

The experimental arrangement for the investigation of photoelectric cross sections of various rare earth elements using ^{241}Am source is shown in the figure 5.1. The detector is shielded by means of lead blocks as in the diagram. A suitable aluminium frame is made for mounting the pellet target with its plane meeting an angle at 45° to the direction of incident gamma rays. The target is kept within a hole of diameter 0.5 cm in the aluminium strip. The ^{241}Am source is placed at a distance of about 10 cm vertically above the target. Hence gamma rays will be incident on the target at an angle of 45° with respect to its plane. NaI (Tl) detector is kept below the target as in diagram so as to detect the X- rays emitted from the target at 90° to the incident rays.

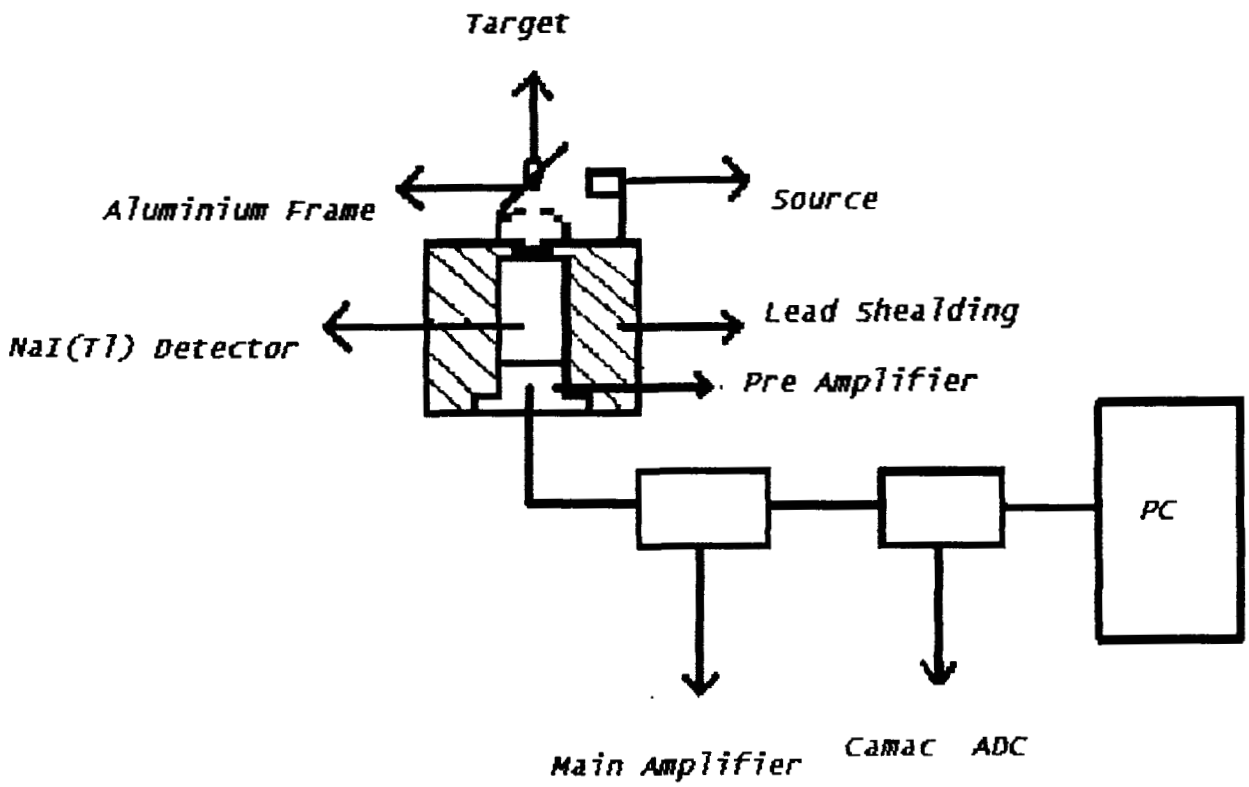


Fig. 5.1 Experimental setup for photoelectric measurements for 59.54 keV gamma rays at 90°.

5.2.1 The source

^{241}Am source is used for investigation of photoelectric effect. The source, emits 59.54 keV gamma rays in addition to a few other lower energy gamma rays, which are not important for the present studies. It has a strength of about 2.4 μCi. Details of the source have been given earlier in section 4.1.

5.2.2 The targets

The targets used were rare earth oxides such as Cerium, Europium oxides etc. To prepare the targets, 1g of KBr is mixed with 500 mg of the rare earth compound, say Pr_2O_3. This mixture is ground well using a mortar and pestle. After grinding, the whole mixture is divided into five equal parts. Then one such portion is kept in the palletizing machine and a pressure of about 15 tones is applied. Here the KBr is used as a binding agent. A beautiful pellet of diameter 1.2 cm is obtained. These types of pellets were used for the above mentioned investigation.

5.2.3 Detector and Electronics

A NaI (Tl) detector was used for measurements of photoelectric cross section. In this detector a NaI crystal of dimension 2" × 1.75" is used. The signals from the detector were processed by standard ORTEC modules. The output of the detector is fed to a pre amplifier.

The output of the pre amplifier is given to a linear amplifier supported by ORTEC. The output of the linear amplifier is supplied to the 4K multi channel analyzer. The software used for this investigation is "Freedom" obtained from Nuclear Science Centre, New-Delhi [1].

5.2.4 Data Collection and Analysis

The spectra of the radiations emitted from the rare earth pellet targets were collected for sufficient time to ensure reasonable statistical accuracy. The background spectra were also collected in between these runs. Net X-ray spectra were obtained by subtraction of the background. Typical spectra obtained are given in fig 5.2 – 5.6. In order to calculate the photoelectric cross section , the net area under the photo peak was taken for each element. The relevant attenuation coefficients for calculating the transmission factor T_i were taken from tabulation of Storm and Israel [2]. A Computer program was developed to calculate the transmission factors of various elements. The photoelectric cross sections were calculated using the formulae given in section 5.1.

5.3 Results

The experimentally measured photo-electric cross sections are listed in table 5.1. They are compared with the theoretical cross sections, obtained from the XCOM compilations [3]. It can be seen that there is reasonable agreement between theory and experiment within the experimental uncertainties.

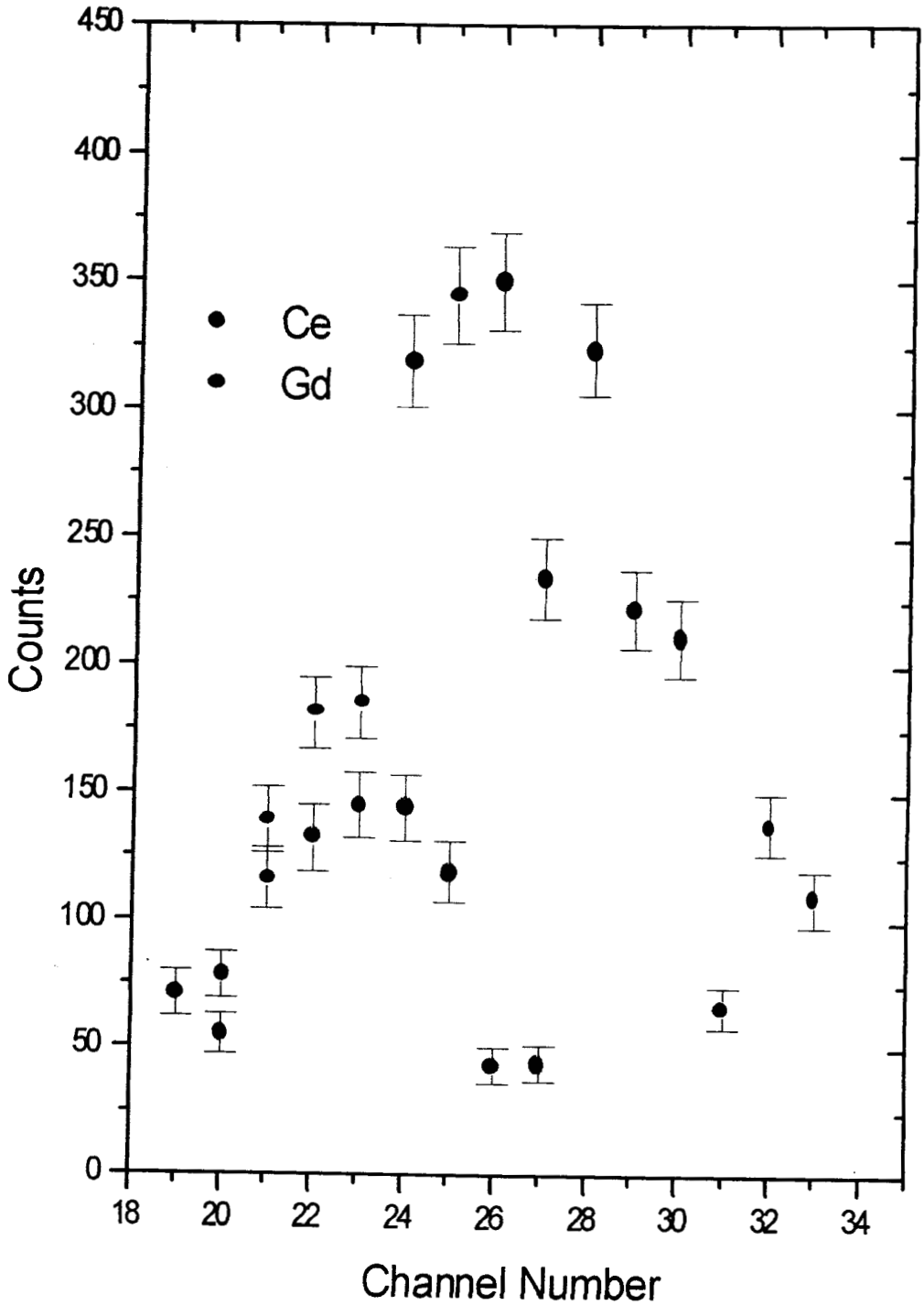


Fig 5.2 - K-X ray spectra of Ce and Gd excited by 59.54 keV gamma rays

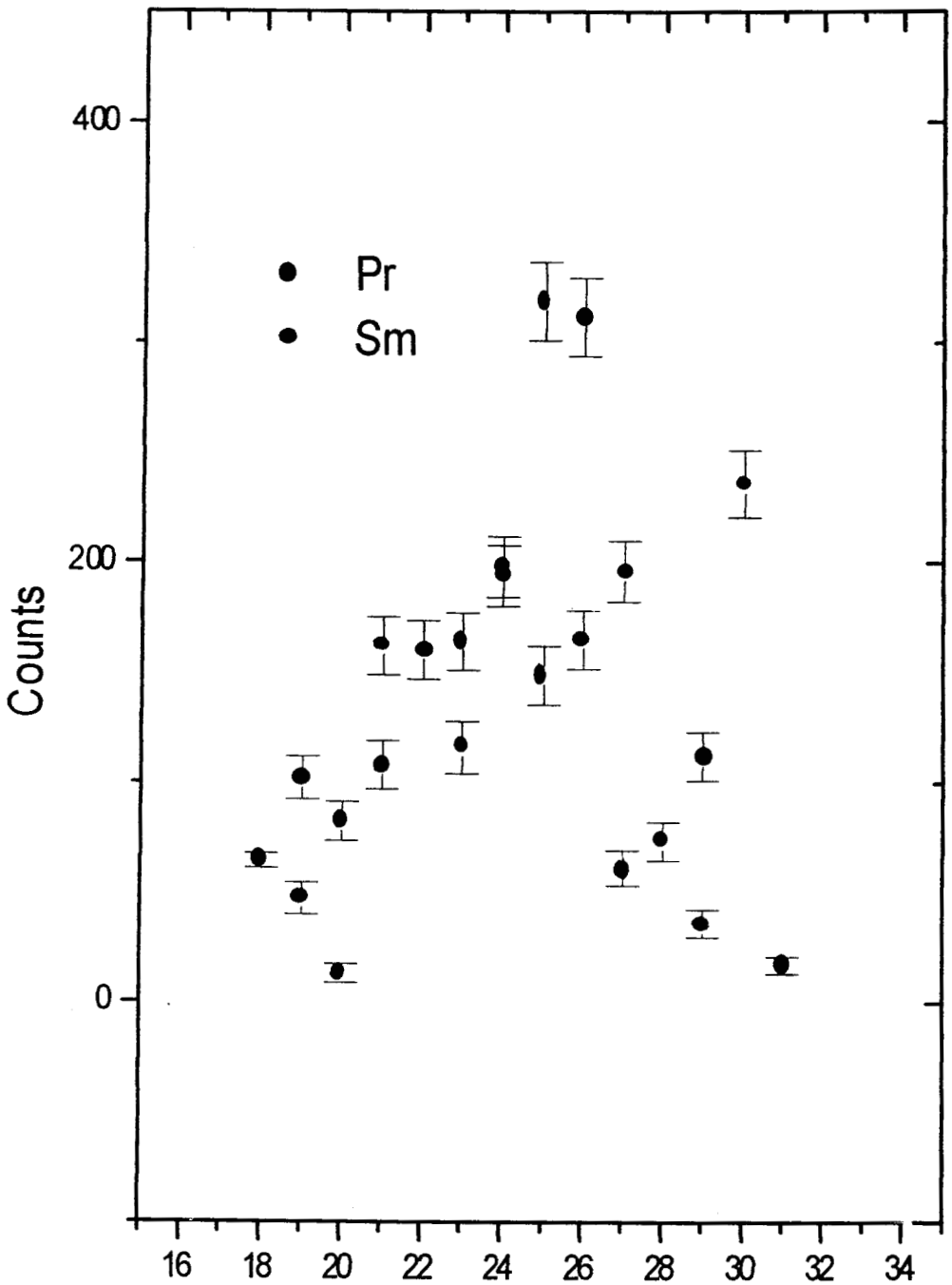


Fig 5.3 - K-X ray spectra of Pr and Sm excited by 59.54 keV gamma rays

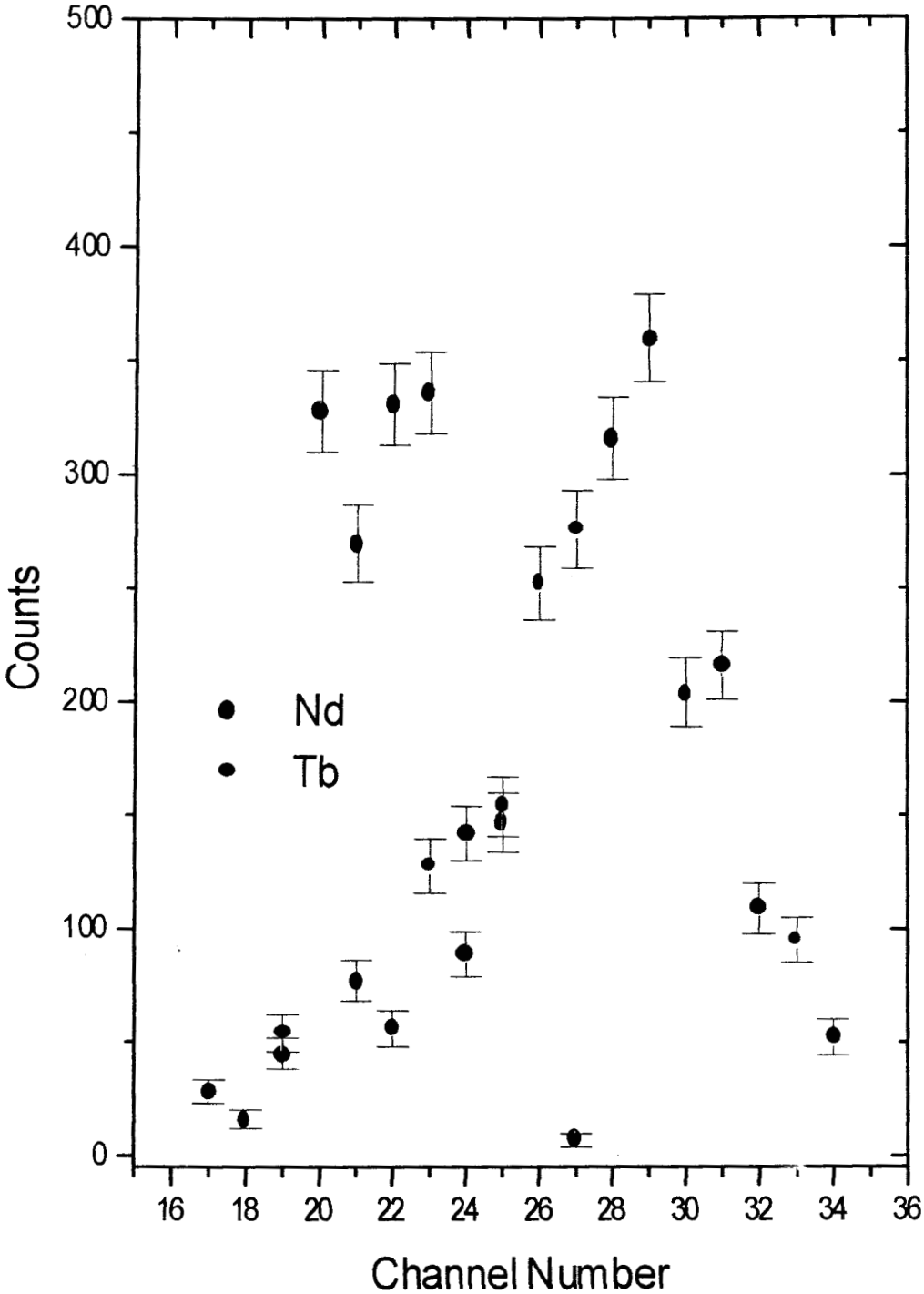


Fig 5.4 - K-X ray spectrum for Gd and Tb targets excited by 59.54 keV gamma rays

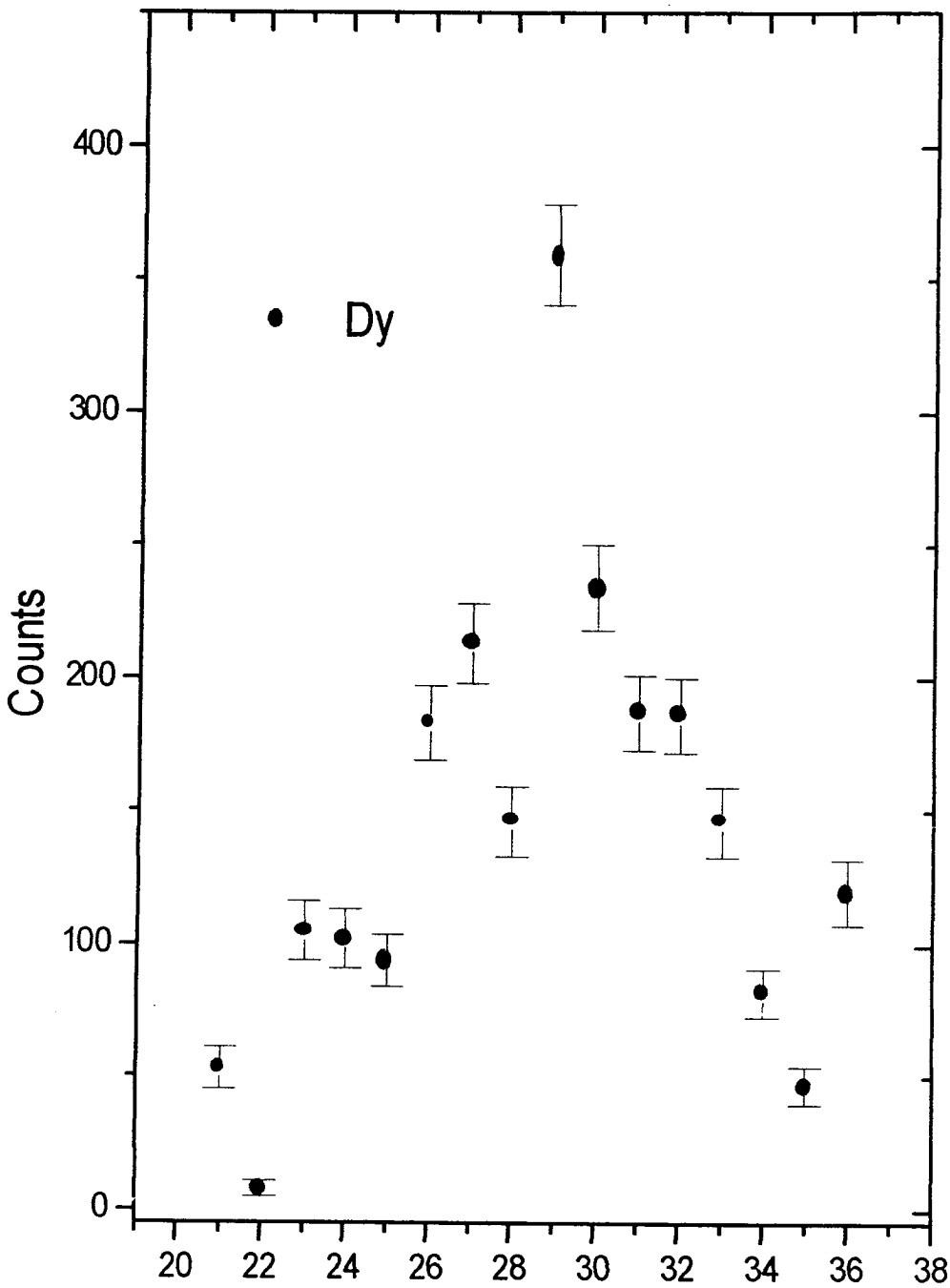


Fig Fig 5.5 - K-X ray spectrum of Dy target excited by 59.54 keV gamma rays

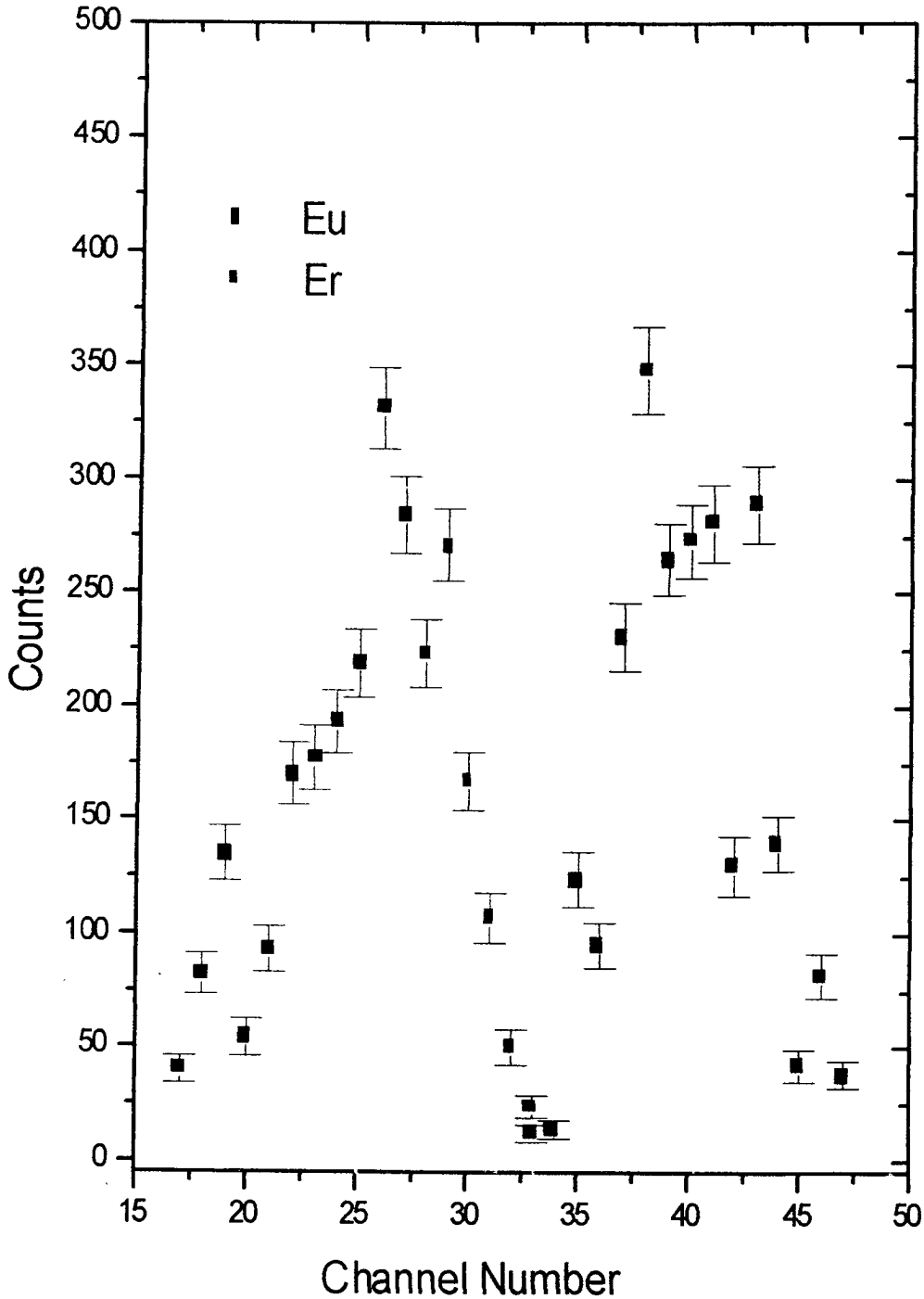


Fig 5.6 - K-X ray spectrum for Eu and Er targets excited by 59.54keV gamma rays

Table 5.1 Experimental photo electric cross sections at 59.54 keV for rare earth elements

Atomic number	Element	σk (barns)	Experiment Theory
58	Cerium	2140(±195)	2144
59	Praseodymium	2033(±239)	2284
60	Neodymium	2335(±328)	2422
62	Samarium	3254(±386)	2712
63	Europium	3730(±421)	2861
64	Gadolinium	3559(±543)	3015
65	Terbium	3173(±452)	3173
66	Dysprosium	2752(±445)	3342
68	Erbium	3032(±449)	3723
69	Thulium	3953(±440)	3920

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3. M.J. Berger and J.H. Hubbel, NIST Standard Reference Data Base (1990)

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CHAPTER VI

GAMMA RAY ATTENUATION MEASUREMENTS IN LEAF AND WOOD SAMPLES

6.1 Introduction

Water is the most abundant constituent of plants and trees. Actual water content of plants and trees vary according to the tissue type and depends on environmental and physiological conditions. The water content typically accounts for about 60 – 80% by weight in non woody parts and 30 – 50% in the woody parts. When leaves and wood dry up, they mainly lose their water content. Information about the water content is essential for many purposes like understanding the metabolic processes in the plants, water diffusion and flow studies etc. Mortatti et al.[1] have used a method to study ten different samples using 662 keV and 59.54 keV gamma rays. Barros_Ferraz et al. [2] used the method to study the density variability in two different samples of pine wood using ^{241}Am gamma rays, with a view to understand their productivity and climatic adaptation. Aguair and Barros_Ferraz [3] developed a new method of water content gradation in wood based on low energy gamma ray attenuation in pine wood samples. They showed that the method is quick, non destructive and has reliably good sensitivities for moisture contents varying from about 90% to 150%. de Miranda et al. [4] studied gamma attenuation in natural wood, dry wood and dry leaves using ^{241}Am gamma rays. They

found that the variation is small among different species. Woods have higher attenuation than leaves, both depending on the water content.

The gamma ray attenuation method has been used to estimate the water content of natural and dried samples of leaves and wood. ^{241}Am gamma rays of energy 59.54 keV have been used in these studies. The following give the details of the experiment and the main results obtained. A preliminary report [5] on the present studies have already been presented at the XIVth National symposium on Radiation Physics held at Amritsar (India) during November 2001.

6.2 Experimental details

6.2.1 Source

The present measurements have been carried out using 59.54 keV gamma rays from a 2.4 μCi ^{241}Am source, procured from Babha Atomic Research Centre, Mumbai. The details of the source are given earlier in chapter IV.

6.2.2 The Set up for absorption measurement

A vertical narrow beam geometry was used in order to reduce the effect of in-scattering on the measured gamma ray attenuation coefficients.

6.2.3 Absorbers

Suitable absorbers were prepared from the leaf and wood samples. For this, the leaf samples were cut in the form of rectangular pieces of dimensions 5 cm × 5 cm. Sets of 3 – 10 such sheets were packed together in between two cardboard frames with a 2 cm × 2 cm central hole, and secured by means of cello tapes. This helped in avoiding corrugation of the leaves during drying. In order to increase the thickness of the leaf sample, another set of leaves was arranged in the same manner and placed over the first one and so on.

In the case of wood, the absorbers were in the form of rectangular sheets of dimensions 5 cm × 5 cm × 1 cm. After the measurement with each species of leaf/wood sample, it was kept in an oven at a temperature of 60° for a few days. This ensures that all the water in the samples have been evaporated away. Care was taken to ensure that the leaf samples did not develop wrinkles. The attenuation measurements were then repeated on the dried samples. The mass of the absorbers was taken on a precision electronic balance both for the fresh and dried samples. Thus the water content of the samples can be evaluated from these mass measurements.

6.2.4 Electronics and Data Collection

The gamma rays were transmitted through the absorbing samples of leaf and wood and detected by a 2" X 1 1/4" NaI(Tl) detector, coupled to a RCA 6810A Photo

multiplier tube, pre amplifier and an ORTEC 571 amplifier. The amplifier output pulses were then fed to a CAMAC based data acquisition and analysis system, consisting of a Kinetic CAMAC crate, crate controller, a 4k Quad ADC, supplied by the Electronics Division, BARC and connected to a Personal Computer through a suitable interface card. A Linux based package, FREEDOM [6], developed at the Nuclear Science Centre, New Delhi was used for the data collection and analysis.

6.2.5 Experimental Procedure and Data Analysis

The ^{241}Am source was placed at a convenient distance from the sample. The gamma rays are allowed to pass through the sample for a time of about 5 minutes. The transmitted spectra is collected on the MCA. From the spectrum, the area of the photopeak corresponding to this thickness of the absorber was determined. Now another sample was added to the earlier one and the spectrum taken. The same measurements were repeated for the rest of the samples. A graph between logarithm of the transmitted counts vs. the absorber thickness was drawn. The graphs were observed to be straight lines.

For each species of leaf and wood, the mass attenuation coefficients were estimated from the attenuation data, using a linear least squares fit.

After carrying out the attenuation measurements with the above samples, the fresh samples were kept in an oven at a temperature of about 60° C for a few days so that the water content in the samples were completely evaporated.

The dried samples were placed near the detector at the absorber position and measurements were repeated to find the attenuation coefficients of the dried samples of each species.

In order to calculate the water content in the fresh samples of wood and leaves, the mixture rule is applied as follows :

$$(\mu/\rho)_{fresh} = (1 - f_0)\,(\mu/\rho)_{dried} + f_0\,(\mu/\rho)_{water} \qquad (6.1)$$

where f_0 is the fractional water content and the (μ/ρ) are the mass attenuation coefficients. From the above equation f_0 can be calculated.

6.3 RESULTS

Tables 6.1 and 6.2 give the results of the present measurements for the leaf and wood samples respectively. The attenuation coefficients for the fresh and dried samples as well as the percentage water contents derived from the attenuation measurements and from direct mass determination, are given in these tables. It is seen that there is good agreement between the derived and directly measured values of the water content in the leaf and wood samples.

TABLE 6.1 : Percentage water content in various plant leaves and corresponding attenuation coefficients

Name	% Loss of water(theory)	% Loss of water(expt)	$(\mu/\rho)_{fresh}$ (cm^2/g)	$(\mu/\rho)_{dried}$ (cm^2/g)
Musa paradisiaca cv nenthran	84.7	83.6	0.201	0.37
Musa paradisiaca cv malavazha	67.2	68.8	0.185	0.297
Musa paradisiaca cv kallanvazha	70.5	70.9	0.169	0.250
Heliconia	71.1	62.3	0.166	0.215
Ficus elastica	78.9	79.3	0.155	0.227
Cocos nucifera	60.0	56.6	0.149	0.166

TABLE 6.2 : Percentage water content in various wood samples and corresponding attenuation coefficients

Name	% Loss of water(theory)	% Loss of water(expt)	$(\mu/\rho)_{fresh}$ (cm^2/g)	$(\mu/\rho)_{dried}$ (cm^2/g)
Psidium gujava	52.7	49.0	0.173	0.208
Samania saman	48.3	34.0	0.148	0.154
Artocarpus hetarophyllus	44.5	32.5	0.159	0.169
Emblica officiualis	38.4	41.4	0.159	0.176
Briddia setusa	42.1	35.7	0.158	0.170

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CHAPTER VII

GAMMA RAY ATTENUATION MEASUREMENTS IN SAMPLES OF VARYING PARTICLE SIZES

7.1 Principle of the experimental method

Compacted sand, clay and soil can be used for shielding of radiation to within safety levels. The grain sizes of the particles in these materials vary with the sample location etc. The void spaces in between the grains depend on the particle size. Consequently, when gamma rays pass through such materials, the attenuation will depend on the extent of the void spaces and hence on the particle size. The effect of the grain size on mass attenuation coefficient of un-compacted sand samples collected from Calicut beach, Neendakara beach and Areekad river as also sugar samples of varying particle sizes and rice grain samples have been subjected to attenuation studies, using ^{241}Am source.

Earlier, Singh et al. [1 - 3] investigated the effect of the particle size on gamma ray attenuation. Appreciable variations have been seen in linear and mass attenuation coefficients with soil grain diameter d for d values between 0.053 and 0.308 mm. The slope of the μ / ρ curve vs. d was found to vary from 1.54 to 0.23 as the gamma energy increased from 81 keV to 1.33 MeV. Smith [4] had studied the effects of voids on μ / ρ. He gave the following relation for the effective attenuation coefficient μ_e :

$$\mu_e = (1 - \nu) / [\, 1 + 0.55\, (s / \mu)\, \nu^2] \qquad \text{----------} (7.1)$$

where ν is the fractional volume occupied by the voids and s is the average distance between voids.

Off hand the above expression seems wrong since when $\nu = 0$, $\mu_e = 1$, irrespective of the true value of μ, which is absurd. We feel that the above expression gives the fractional value of μ_e as compared to μ.

7.2 Theory

Materials like sand, sugar etc actually exist in the form of particles of different grain sizes. Although the shapes of these particles are not spherical, for a theoretical treatment we will assume them to be of spherical shape with variable radius r. First, let us consider a fine beam of gamma rays of rectangular cross section of side 2r and intensity I_o photons per second over this rectangular cross section. The number of photons falling on the area of cross section πr^2 of the spherical particle and which will be attenuated on passage through the particle, is $I_o\, (\pi\, r^2 / 4\, r^2) = \pi\, I_o / 4$ and the number passing un-attenuated through the vacant space outside the area of cross section of the spherical particle is $(4 - \pi)\, I_o / 4$.

In order to calculate the attenuation through the particle, let us consider the sphere as being divided into a large number of cylindrical shells with axis along the direction of incidence of the gamma rays and passing through the center of the sphere. Figure 7.1 gives a schematic diagram of a single sphere and one such cylindrical shell of radius ρ.

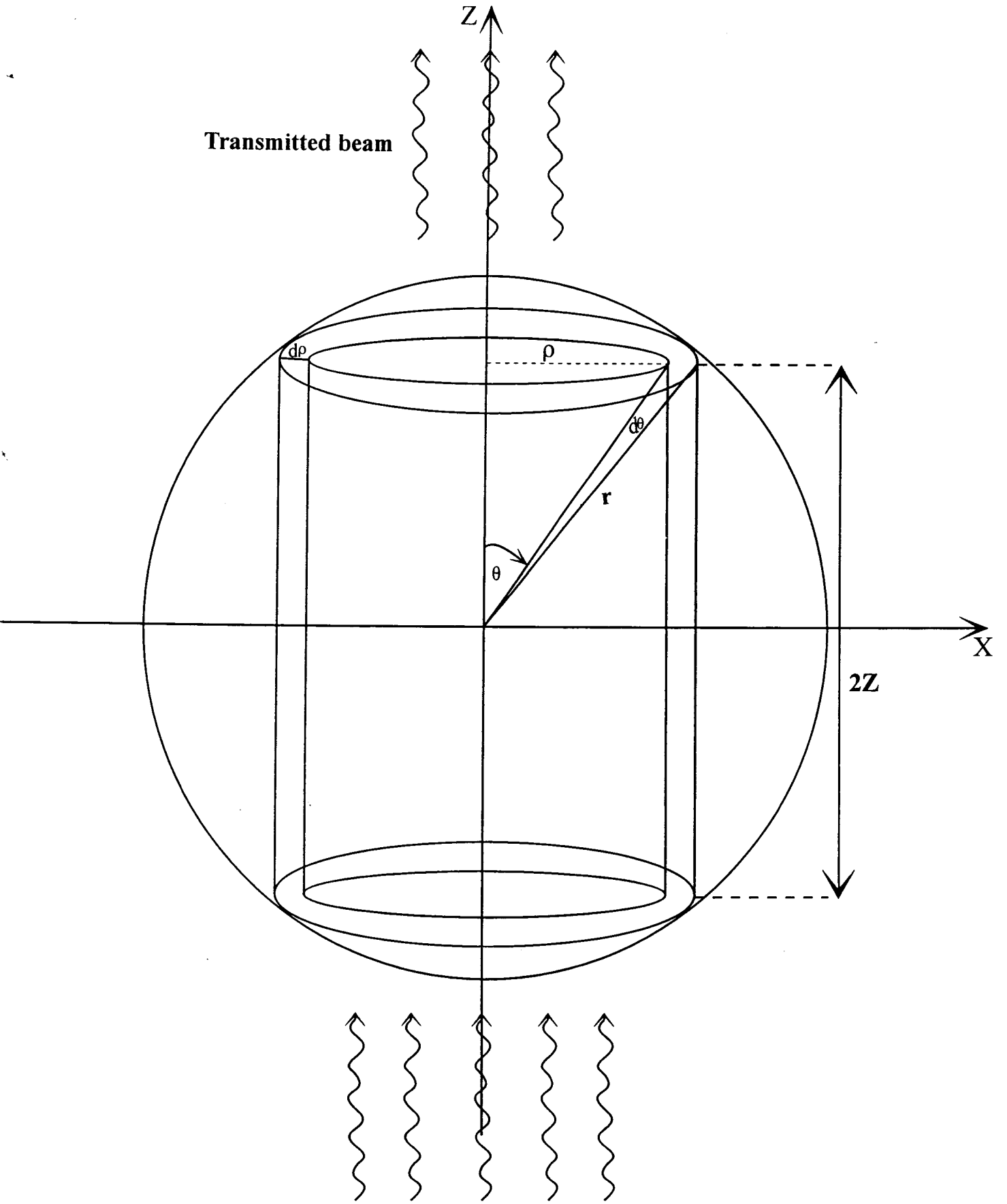

Fig. 7.1 Schematic diagram showing cross sectional view of the spherical particle for calculation of gamma ray attenuation.

The Z axis is taken along the direction of the axis of the cylinders. The area of cross section of the cylindrical shell is $2\pi \rho \, d\rho$. From the diagram, $\rho = r \cos\theta$, where θ is the spherical polar angle. The thickness of the shell is $d\rho$ and its height is $r \cos\theta$. The number of photons falling on the top of the shell is given by

$$dI' = (I_o / 4r^2) 2\pi \rho \, d\rho$$

$$= (\pi I_o / 2) \sin\theta \cos\theta \, d\theta \quad \text{---------- (7.2)}$$

Number of gamma rays transmitted through the shell is given by

$$dI = dI' \exp (- \mu 2r \cos\theta)$$

Hence on integration $I = (\pi I_o / 2) \int_0^{\pi/2} \exp (- \mu 2r \cos\theta) \sin\theta \cos\theta \, d\theta$

Transforming variables by putting $t = \mu 2r \cos\theta$, we get

$$I = (\pi I_o / 2) (1 / 2 \mu r)^2 \int_0^{2\mu r} t \exp (- t) \, dt \quad \text{----------(7.4)}$$

Finally one obtains

$$I = (\pi I_o / 2) (1 / 2 \mu r)^2 [1 - e^{-2\mu r} (1 + 2 \mu r)] \quad \text{-------- (7.5)}$$

If the material in the spherical particle is redistributed uniformly over the area of the square of length 2r and over thickness 2r, the effective attenuation coefficient is μ' such that we get the same transmitted intensity I, then

$$I = I_o e^{-2\mu' r} \quad \text{---------(7.6)}$$

From 7.4 and 7.5 we can find μ'.

7.3 Details of the experimental setup

The experimental arrangement used in the present investigation is the same as used for the measurements described in chapter IV (shown systematically in fig. 4.1). A conventional narrow beam set up was used.

7.3.1 The absorbers

The sand samples were prepared by sieving the oven-dried sand through a set of standard sieves with sizes between 50 μm and 2mm. Equal quantities of the sand is taken in a weighed plastic sheet and weighed on an electronic balance. Ten such measured samples of the same grain size were used as the absorbers. To calculate (μ/ρ), the density values of sand samples were measured using the relation ρ = mass/volume. For preparing sugar samples and rice grain samples of varying particle sizes, commercially available sugar / rice grains, of particle size ~ 2 mm, was ground in a mixer-grinder and then subjected to sieving in sieves of different mesh sizes.

7.3.2 Detector and Electronics

The same detector and electronic circuits used for the previous experiments detailed in the earlier chapters were used for the present studies also.

7.3.3 Data collection and Analysis

First of all, the weighed quantity of sand of grain size of 90 μm is taken in a small beaker. By means of a small piston, the thickness of sand in the beaker is made uniform. The beaker containing the given amount of sand was kept between the detector and the source. For this thickness of the absorber, transmitted gamma ray spectrum was collected for sufficient time to ensure reasonable statistical accuracy. The background spectra were also collected in between these runs. Net absorption spectra were can be calculated by subtracting background from the actual spectrum. The experiment was repeated for the other weighed samples of the same grain size and the counts were measured with the help of NaI(Tl) detector. Thereafter, a graph is plotted between logarithm of counts along Y axis and mass per unit area of the samples along X axis. The slope of the graph is extracted. to give the mass attenuation coefficient. Thereafter the experiment was repeated for the other grain sizes say 125 μns, 150 μns, 1mm, 2mm etc.

7.4 Results and Discussion

Results of the theoretical calculations for the variation of the mass attenuation coefficient as a function of the grain diameter is shown in Fig. 7.2. It can be seen that as per present calculations, the total variation in me as the grain diameter increases to about 0.4 cm is only 2%. As per Smith's results, this change is about 22%, which does not agree with the experimental values.

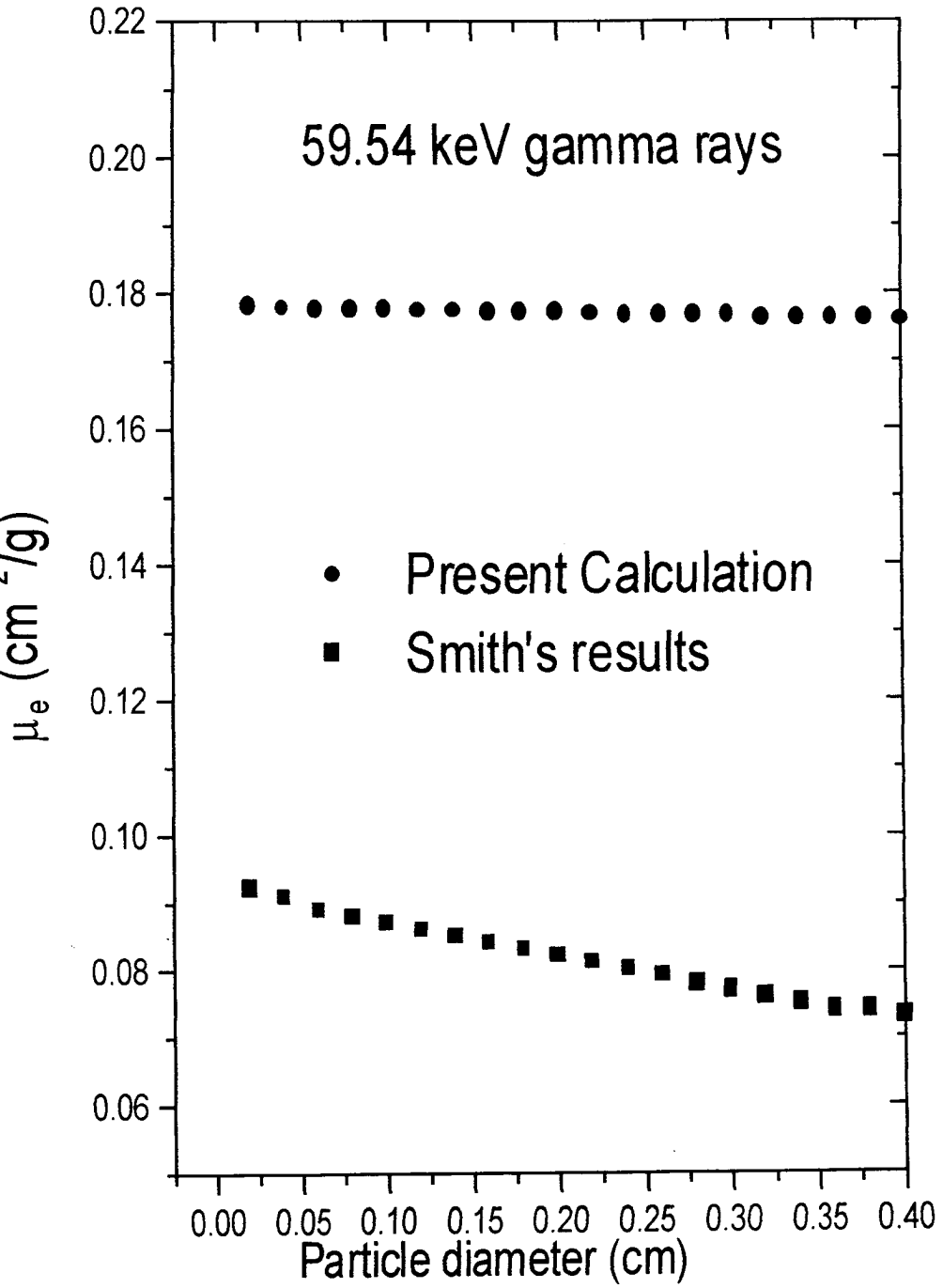

Fig 7.2 - Variation of mass attenuation coefficient vs. grain diameter

Variations of mass attenuation co-efficient with grain diameter are shown in Fig. 7.3 and 7.4 for sugar and one sample of sand. In these figures, the theoretical results are also shown. From these μ vs d plots, it is clear that for the energy 59.54 keV, μ decreases with increase of d for these samples. Some of the sand samples collected from the Neendakara beach showed abnormal increases at some grain sizes. This was identified as due to presence of excess iron or titanium in these samples.

For a sample of rice grains, however, a different trend was observed for the variation of the mass attenuation coefficient with grain diameter. This result is shown in fig. 7.5. This could not be explained, unless we assume that the composition itself varies with grain diameter.

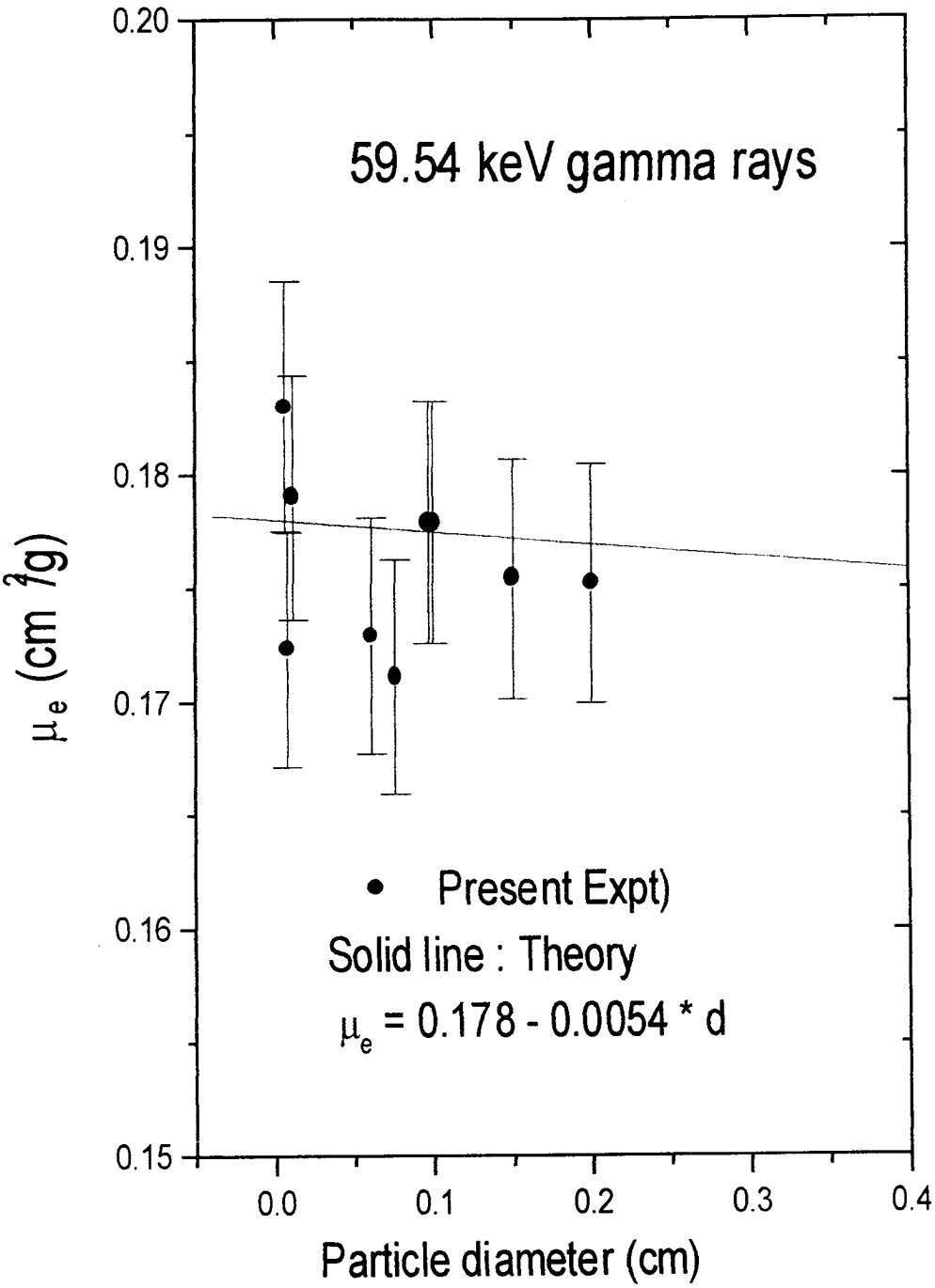

Fig 7.3 - Variation of μ_e vs grain diameter for one brand of sugar for 59.54 keV gamma rays

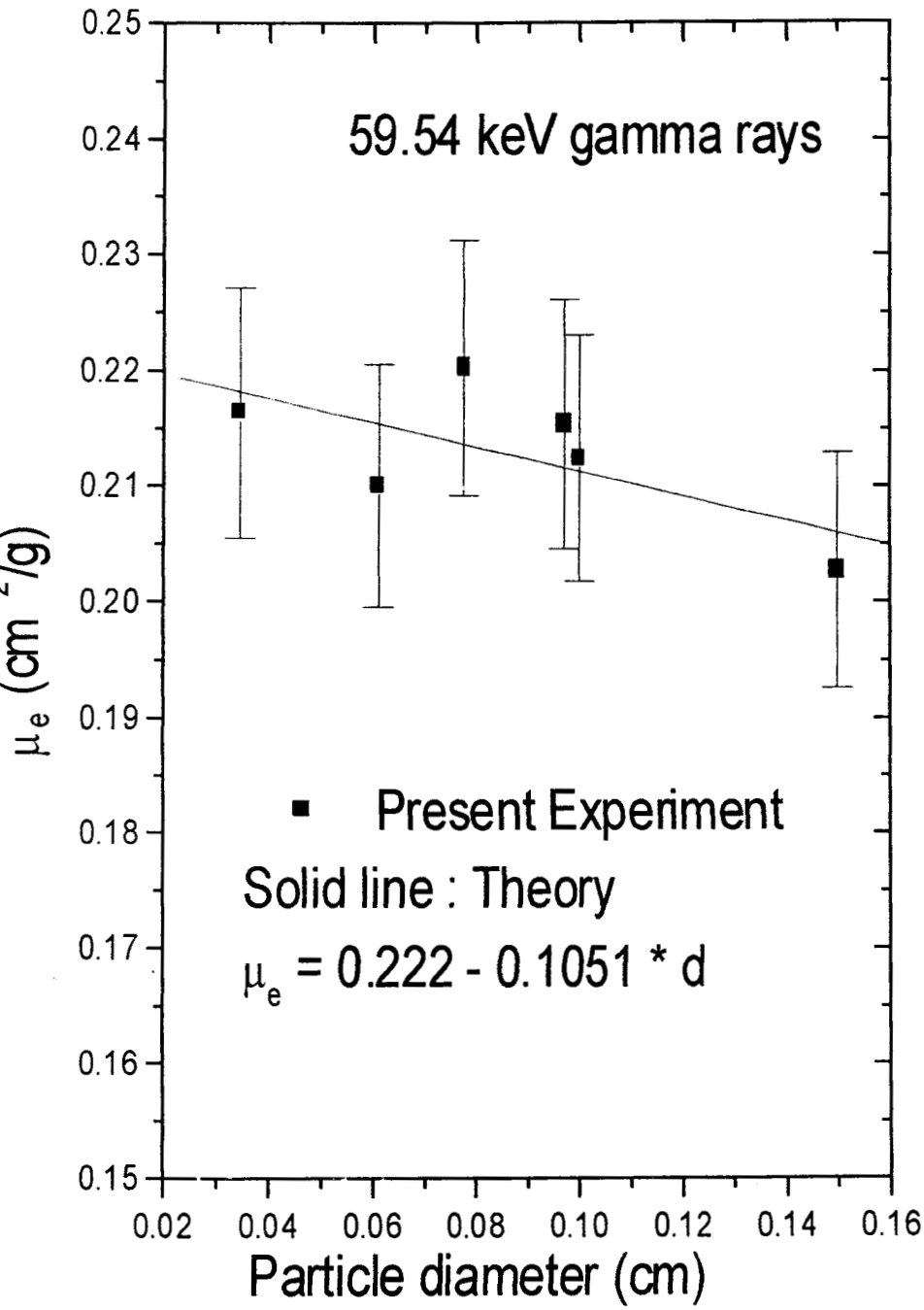

Fig 7.4 Observed variation of μ_e vs grain diameter for one type of sand for 59.54 keV gamma rays.

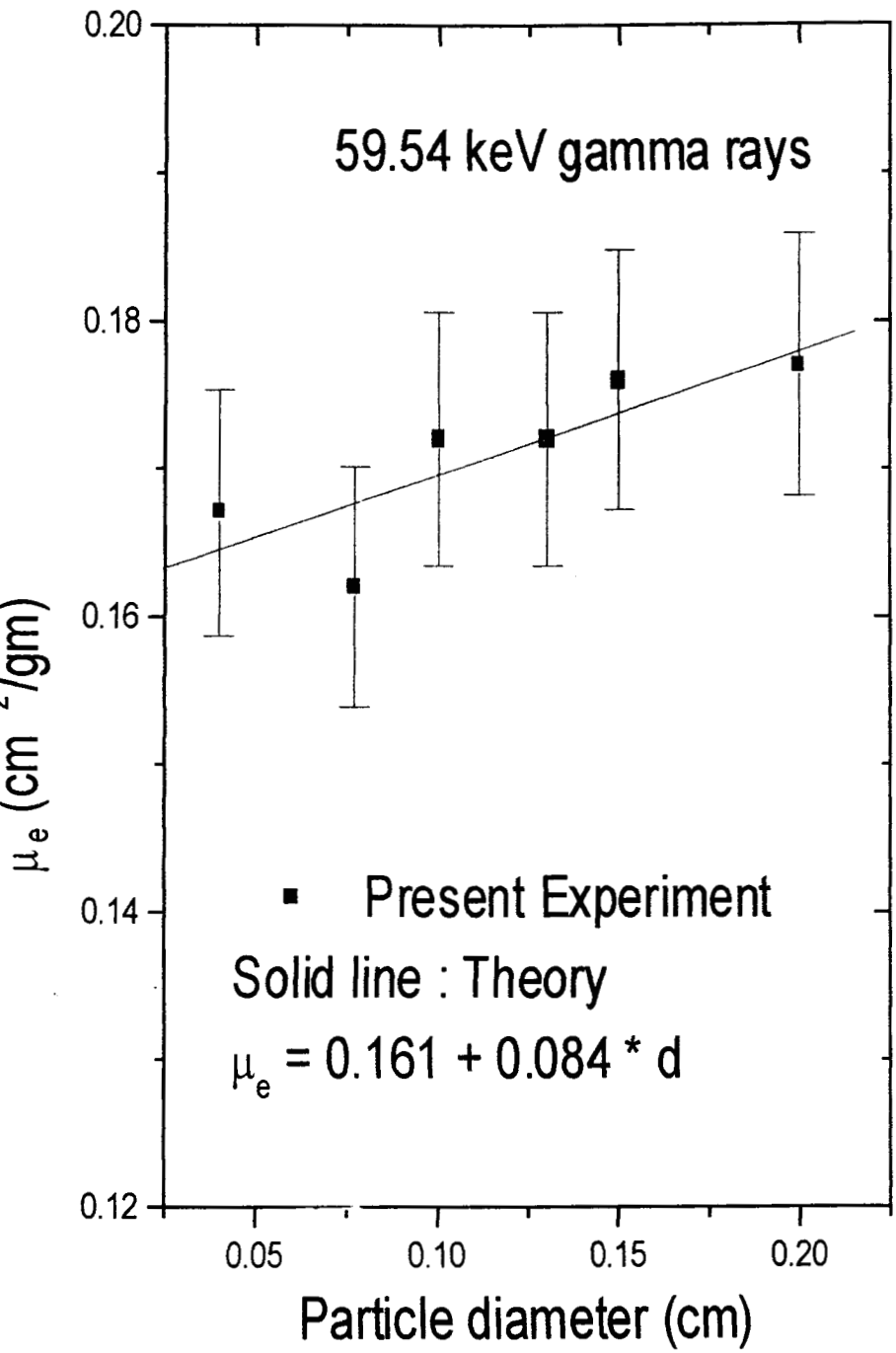

Fig 7.5- Variation of μ_e vs. grain diamtere for one brand of rice for 59.54 keV gamma rays

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