CHAPTER - 1

I N T R O D U C T I O N

The passage of electromagnetic radiation (X-rays and gamma rays) through matter is characterized by the exponential law of attenuation. The processes resulting in attenuation are

a) elastic scattering

b) Compton scattering

c) photoelectric effect

d) pair production for photon energies above 1 MeV

In the elastic scattering process the direction of the incident photon is altered with no change in energy. Four different types of elastic scattering processes contribute to the total elastic scattering of gamma rays. They are the nuclear resonance scattering (N), Delbruck scattering (D), nuclear Thomson scattering (T) and Rayleigh scattering (R). The four processes occur coherently with each other. This means that if the atomic elastic scattering is described in terms of a differential scattering cross section

$$\frac{d\sigma^{el}}{d\Omega} = |A|^2$$

then the elastic scattering amplitude A must be obtained as a combination :

$$A = A^N + A^D + A^T + A^R$$

Of the elastic scattering processes, Rayleigh scattering is by far the most important and dominates other elastic processes in the photon energy range of few keVs to tens of keVs. It takes place from the atomic bound electrons provided that the electrons do not receive sufficient energy to eject them from the atom. The essential feature of Rayleigh scattering is that the internal energy of the atom remains unaltered in the interaction. The momentum and polarization of the atom may be modified during the process. The cross section of the process is given by the square of the modulus of the scattering amplitude A^R :

$$\frac{d\sigma^R}{d\Omega} = \left| A^R \right|^2$$

While using the amplitude to calculate the differential cross section, the photon polarization is taken into account. For linearly polarized photons, these amplitudes are expressed as components ($A^R_{\parallel}$) parallel and ($A^R_{\perp}$) perpendicular to the plane of scattering. The unpolarized cross section (in units of barns/sr, 1b = 10^{-24} cm^2) results from summing over final photon polarizations and averaging over initial photon polarizations as :

$$\frac{d\sigma^R}{d\Omega} = \frac{1}{2}\left(\left| A^R_{\parallel} \right|^2 + \left| A^R_{\perp} \right|^2 \right)$$

For scattering of low-energy photons, effects of electron binding are crucial. It is particularly of interest to carry out

investigations at photon energies of the order of electron binding energies. The region below photon energies of about 100 keV had been of considerable theoretical uncertainty in the past due to the proximity of the photoelectric absorption edges. In recent years considerable developments have taken place in the field of elastic scattering of photons of atoms. Very accurate results have been obtained through the use of fast computers in theoretical calculations. On the experimental front, the availability of high resolution solid state detectors has made it possible to make more detailed studies of gamma spectra than is possible with a conventional NaI spectrometer. All these have contributed to significant reduction in uncertainties. While generally satisfactory agreement has been achieved with experimental studies of X-ray and gamma ray scattering from atoms representing an improvement upon previous theoretical calculations, the understanding of the dramatic effects of the anomalous scattering region near atomic inner-shell edges is far from complete. In the regions within several hundred electron volts of the edges, precise cross section data are at present dependent on experimental measurements.

The present thesis is based on the work done by the author in the field of photon interactions in matter and pertains mainly to the coherent (elastic) scattering of photons below 100 keV with particular emphasis on the anomalous dispersion effects on the cross sections at energies near (both above

and below) K-absorption edges of target atoms.

In general, the effects of interaction of gamma rays in matter are studied in two ways:

i) attenuation experiments in which the number of photons transmitted through absorbers of different thicknesses is determined; and

ii) photon-atom collision experiments in which the energy of the transmitted radiation is analysed, and the fractional number of photons scattered coherently (or incoherently) at a given angle is measured.

The experimental results presented in the thesis were obtained from three separate experiments. They are -

1. A narrow beam attenuation experiment on the 'good geometry' arrangement using a NaI detector.

2. A small angle scattering experiment for the measurement of cross sections of unresolved total (coherent + incoherent) scattering in the momentum transfer range 0.012 - 0.036 mc using shadow cone type of geometry and a NaI detector.

3. A large angle scattering experiment for the measurement of elastic scattering cross section in the momentum transfer range 0.0116 - 0.231 mc using a plane scatterer transmission geometry and a high resolution intrinsic germanium detector.

The investigation was carried out using in all cases gamma ray photons of energy 43 and 59.5 keV emitted by the radioactive ^{241}Am source. The aim was to try an evaluation of the rigorous validity of new calculations as well as the conventional form factor theories in the light of experimental data obtained by the author together with the other accurate low photon energy measurements performed in recent years.

The topical organization of the thesis is as described in the following.

In Chapter 2, we begin with a brief outline of the basic theoretical framework for the treatment of photon-atom interaction. A summary of the developments in the theory of the atomic elastic photon scattering from bound electrons (Rayleigh scattering) is given. Three other elastic scattering processes occur coherently with Rayleigh scattering. These processes are not treated as they make very small contribution to the total elastic scattering in the range of photon energies involved (< 100 keV). The development in the calculation of Rayleigh scattering amplitudes from the non-relativistic domain of momentum transfer in the Thomas - Fermi model of the atom to the relativistic Dirac-Slater and Hartree - Fock models by using various form factor approaches and the numerical S-matrix element perturbative approach is discussed. An intercomparison of theories is made by presenting theoretical cross sections

for the elastic scattering of ^{241}Am gamma rays by various targets. These cross sections have been computed using non-relativistic form factor (NRFF), relativistic form factor (RFF), and modified relativistic form factor (MRFF) values readily obtainable from the available tabulations[1-3]. Numerical S-matrix results were obtained from the tables of cross sections compiled by Kane et al[4].

The need and usefulness of the dispersion corrections to the Rayleigh scattering amplitudes at photon energies near absorption edges of target atoms is discussed in Chapter 3. The method of using the dispersion integral (Kramers-Kronig relation) to get forward scattering correction terms from the photoelectric cross section data is briefly outlined. Also presented are the results of our Rayleigh scattering calculations at different angles of target atoms ranging in atomic number from Z = 42 to Z = 73 at the photon energy of 59.54 keV using anomalous scattering factors f' and f" calculated recently by Creagh and McAuley[5]. A comparison with the numerical S-matrix predictions of Kissel - Pratt and Roy (KPR) is attempted.

In Chapter 4 we describe the experimental arrangement and the method for measuring the total photon-atom interaction cross sections and the whole atom differential elastic scattering cross sections at small and large angles. The results obtained from the measurements are presented together with the errors estimated and corrections employed.

Finally, in chapter 5, the results of the present set of measurements in conjunction with the results of other recent measurements are compared with the various theoretical calculations of Rayleigh scattering so as to reveal the trend of behaviour of the predictions of the theory. We also summarise the main aspects of the results which we have found most important when preparing the thesis.

The present work was carried out under the Faculty Improvement Programme of the University Grants Commission, India during the period 1987-90.