CHAPTER - 1

INTRODUCTION

The interaction of photons with matter through the processes of photoeffect, scattering and pair production has continued to remain a subject of investigation for a long time. This is due to the continuing developments in the theoretical calculations of these processes as well as revolutionary developments in the experimental techniques involving sophisticated measuring instruments.

The photoeffect and pair production processes are dominant in the low and high energy regions of incident photons respectively, while the scattering process is important in the intermediate energy range. The scattering of photons may be incoherent (inelastic) or coherent (elastic). The scattering of photons by atomic electrons in which the photon undergoes a change in both momentum and energy and the state of the atom after scattering is either excited or ionised is known as incoherent or inelastic scattering. The coherent or elastic scattering of photons is divided into four different processes. The contribution made by bound atomic electrons to elastic scattering is known as Rayleigh scattering. It takes place if the electron returns to its original state after interaction. The atom as a whole absorbs the momentum change and the scattered photon has the same energy as the incident and there is a relation in phase among the scattered photons from different electrons. The elastic scattering by nucleus is decomposed as nuclear Thomson scattering (scattering by charge of the nucleus), nuclear resonance scattering (nuclear analogue of Rayleigh scattering) and finally Delbruck scattering in which the photon is scattered by the Coulomb field of the nucleus. All these four elastic scattering processes, in which the scattered photons have the same energy as the incident, combine coherently.

The aim of the present thesis is to present an evaluation of all available data and the data obtained by the author by investigating the coherent scatteing of photons over a wide range of photon energy on target atoms of low, medium and high atomic numbers for scattering angles from 1° through 150°. The need for such evaluation and new measurements arises from the following considerations. The different elastic scattering processes act simultaneously and since there is no method of experimentally determining the contribution of a particular type of elastic scattering process exact theoretical knowledge of scattering amplitudes of all these processes must be available to us so that we can pay attention to a particular type of scattering process while attempting experimental measurements. In recent years there have been new developments in the theoretical calculations of Rayleigh and Delbruck scattering amplitudes covering a wide range of photon energies and scattering angles. The only exact calculation of Rayleigh scattering amplitudes available until recently was due to Brown and his co-workers[1,2,3,4]. These calculations were restricted to only K-shell electrons of mercury atom and photon energies of 0.164, 0.367, 0.654 and 1.308 MeV. The experimental researchers of the last decade in this field of elastic scattering of photons in the energy range upto 1.33 MeV made use of these calculations by making interpolations and extrapolations resulting in large errors in the theoretical calculations of elastic differential scattering cross sections. The situation has considerably improved after the publications of shell wise Rayleigh scattering amplitudes for a large number of target atoms and photon energies first by Johnson and Cheng[5] and later by Kissel, Pratt and Roy[6,7,8]. There are now tabulations[9,10] of non-relativistic and relativistic form factors. The form factor approximation to predict Rayleigh scattering is widely used in the calculation of elastic scattering cross sections and attenuation co-efficients. Florescu and Gavrila[11] have presented Rayleigh scattering amplitudes for K-shell electrons through a different approach. The calculations of Delbruck scattering amplitudes by Papatzacos and Mork[12] mark a definite improvement over those made by Ehlotzky and Sheppy[13] so far as the real or dispersive part of the Delbruck amplitudes is concerned.

In view of the developments in the theoretical calculations of Rayleigh and Delbruck scattering amplitudes and the limited data available from experiments it is necessary to investigate coherent scattering experimentally to find the regions of validity of these theories. The purpose is to find out the relation of facts observed before through extensive evaluation of different theoretical calculations of Rayleigh scattering amplitudes with a new set of experimental data obtained by the author using radioactive isotopes as sources of gamma ray photons in the energy range of 60 KeV to 2 MeV for a better understanding of the gamma ray coherent scattering process.

Of special interest will be the investigation of coherent scattering of low energy gamma ray photons by bound electrons in the vicinity of photoelectric absorption edges of high Z scatterer elements. The present experimental results together with results of some other recent measurements by other workers will be used in a new way to compare the different theoretical calculations of Rayleigh scattering amplitudes and to find the region of applicability of these calculations as a function of momentum transfer. Rayleigh scattering dominates over all other coherent scattering processes upto the photon energy required for pair production. It is of considerable interest to investigate the coherent scattering of gamma ray photons upto photon energy of 1 MeV. There have been a very few experimental results on coherent scattering cross sections in the photon energy range 100 KeV to 1 MeV, so far as small scattering angles and consequently small momentum transfers are concerned. An extensive data of experimental scattering cross sections with photon energies of 0.084, 0.145, 0.206, 0.662, 1.115 and 1.33 MeV using scatterer elements of atomic numbers ranging from Z = 3 to 90 will be presented.

For photon energies above the threshold for pair production and for target atoms of high atomic numbers such as Lead and Uranium, the contribution of Delbruck scattering becomes significant compared to other elastic scattering processes. The real or dispersive part of Delbruck scattering in which the photon is scattered by the "virtual pairs" formed by the Coulomb field of the nucleus has remained a controversial subject of investigation for quite a long time. Experiments[14,15] done with photon energy of 2.754 MeV using different high Z target elements yield experimental data differing from theoretical calculations at most of the scattering angles, though the contribution of the real part of the Delbruck scattering is established. Earlier experiments[17,18,19] with photon energy of 1.33 MeV from Co-60 isotope also did not agree with the theoretical calculations of the day.

Though the situation has improved considerably so far as the theoretical calculations of Rayleigh amplitudes are concerned, the exact values of both real and imaginary parts of L, M and N shell amplitudes are still not available for photon energies greater than 0.889 MeV. It is also within the scope of the present thesis to compare various ways of estimating these inner shell Rayleigh amplitudes.

A brief description of the developments of the theoretical calculations of Rayleigh and Delbruck scattering processes leading to the "state of the art" scattering amplitudes will be given in Chapter 2. Descriptions of the experimental arrangements for measuring cross sections for low, medium and high Z target elements over energy range of 0.084 - 1.33 MeV and scattering angles 1° - 20°, and for high Z target elements over photon energy range 1.115 - 2 MeV and scattering angles 30° - 150° are given in Chapter 3. In Chapter 4 a detailed discussion of the various methods of obtaining inner shell Rayleigh amplitudes and the method of using the "state of the art" scattering amplitudes for all elastic scattering processes to calculate the differential coherent scattering cross sections will be attempted in Chapter 4. In Chapter 5 comparisons of present experimental results with data from some other recent measurements are made with different theories concerning coherent or elastic scattering of photons so as to reveal the trend of behaviour of these theoretical calculations as a function of momentum transfer.