P R E F A C E

Photon - atom interactions of gamma rays in matter have been studied for a long time and in recent years there have been new theoretical calculations for several elementary scattering processes. The coherent elastic scattering of X-rays and low-energy gamma rays by bound atomic electrons (called the Rayleigh scattering) in the vicinity of photoelectric absorption edges of various scatterer elements is a subject of current interest. For gamma ray energies below 100 keV, Rayleigh scattering is the only significant elastic scattering process. The problem in predicting Rayleigh scattering cross sections below photon energies of 100 keV concerns the rapid variation near the K-shell photoionization thresholds, commonly identified as the anomalous scattering. Recent interesting theroetical work relevant to the description of anomalous scattering of photons from atoms, at energies near regions of atomic excitation and ionization, include calculations of (i) Rayleigh scattering amplitudes in the independent particle approximation based on second order quantum electrodynamic S - matrix formalism (ii) anomalous dispersion corrections to forward Rayleigh scattering amplitude by Creagh and McAuley. We have attempted a verification of these calculations using new measurements of differential scattering cross sections at small and large angles at the photon energy of 59.54 keV.

The work presented in this thesis addresses to what extent the results of new theoretical calculations of elastic photon-atom scattering compare with those formerly in use (namely, the various form factor formulations) and how theoretical predictions compare with recent experiments in the photon energy range for which anomalous scattering is observed.

A number of low-energy photon - atom collision experiments have been made in recent years to determine the elastic scattering cross sections and their angular variation using advanced detection capabilities. We have measured the angular distribution of the Rayleigh scattered photons off the target atoms ranging in atomic number from Z = 29 to z = 82 for the 59.54 keV gamma rays at the scattering angles 5^{o} - 165^{o} (momentum transfer range 0.01 - 0.23 mc). The results are presented, along with the results of other more recent experiments and the latest theoretical calculations, in such a way as to exhibit the degree to which various calculations show unity in their predictions with the relatively accurate experimental data. Such an evaluation is judged to be useful in view of the fact that it reveals the trend of behaviour of the cross section data as the incident photon energy crosses the K - shell photoionization thresholds of the scattering atomic system.

The investigation reported in the thesis is centered around:

(i) a critical survey of the existing theories of atomic elastic scattering of X-ray and low-energy gamma ray photons; (ii) an evaluation of the utility of dispersion corrections (also called anomalous scattering factors) in improving the form factor calculation of atomic elastic scattering near the absorption edges of target atoms; and
(iii) a critical analysis of the new results together with some other recent results of elastic scattering measurements in terms of the available predictions of theory.

After a careful scrutiny of the status of all available theoretical predictions of Rayleigh scattering in relation to each other, and with experimental data, the following trends were noted.

1. For incident photon energies (E) far above the K-edges (E_K) of target atoms, the theoretical predictions based on the S-matrix calculations of Kissel-Pratt-Roy (KPR) and various form factor formulations appear to be in close agreement. The measured elastic scattering cross sections are generally in reasonable accord with the predictions of theory.

2. At photon energies with E/E_K greater than 1 and in the range of moderate to high momentum transfer, the experimental

results show better agreement with theory.

3. A systematic departure from agreement with theory is apparent at the smallest angles of scattering (i.e. low momentum transfer). This is particularly so for photon energies with E/E_k less than 1.

4. In general, the experimental data overwhelmingly support the second order perturbation calculations of KPR and are smaller than the relativistic form factor calculations (RFF) showing better agreement with modified relativistic form factor (MRFF) predictions.

5. There are scattered deviation between available experimental data and state-of-the-art S-matrix calculations of KPR near K-shell thresholds of atoms. But these deviations do not involve any evident systematic trend. Further work, both on theory and experiment, will be needed.

The results obtained from the experiments performed in course of the investigation were published in journals under the following references.

1. Small angle scattering of photons at low energies. Can. J. Phys. 66, 987 (1988).

2. Study of anomalous dispersion in elastic scattering of 59.5 keV photons at K-absorption edges of target elements.

   J. of Phys. B : At. Mol. Opt. Phys. 22, 1175 (1989).

3. Lower energy photon cross sections near atomic shell edges.

   Can. J. of Phys. 68, 244 (1990).

4. Experimental results on low energy photon-atom scattering and a critical analysis of the data in the vicinity of K-absorption edges.

   Phys. Rev. A, 41, 5869 (1990).

Publications 1 - 4 listed above are appended to the thesis in support of the candidature and also to serve as ready reference. In fact, all the results have been discussed in greater detail in the thesis in their final form.

The present investigation has been a collaborative venture. The author, on his part, has actively participated in the setting up of the experiments, day to day maintenance, and recording of the data. The analysis of the data and the interpretations are the author's contribution.

SOURCES OF INFORMATION

The work of others from which the general information for the present work was obtained are listed below.

I. Elastic scattering of γ-rays and X-rays by atoms - P.P.Kane, Lynn Kissel, R.H.Pratt and S.C.Roy, Phys. Rep. Vol. I40, No. 2, I986.

2. Elastic photon-atom scattering of 59.54 keV photons - Lynn Kissel, Sandia Report, SAND 84-0294, UC-34A,I984.

3. X-ray dispersion corrections - D.C.Creagh and W.J.McAuley, International Tables for Crystallography,Vol C, 4.2.6,I989.

4. Atomic form factors, incoherent scattering functions, and photon scattering cross sections - J.H.Hubbell, W.J.Veigele, E.A.Briggs, R.T.Brown, D.T.Cromer, and R.J.Howerton, J. Phys. Chem. Ref. Data 4, 471, I975.

5. Relativistic atomic form factors and photon coherent scattering cross sections - J.H.Hubbell and I. Overbo, J.Phys. Chem. Ref. Data, 8, 69, I979.

6. Small angle Rayleigh scattering of photons at high energies : tabulations of relativistic HFS modified atomic form factors - D.Schaupp, M.Schumacher, F.Smend, P.Rullhusen, and J.H.Hubbell, J.Phys. Chem. Ref. Data, I2, 467, I983.