Review of photon attenuation measurements

Chapter 2

Review of photon attenuation measurements

2.1 Introduction

Studies on photon attenuation measurements have so far been, primarily aimed to arrive at quite reasonable values of attenuation coefficients and cross sections that deviate a minimum from theory. The basic components of measurements on attenuation being source, detector and the absorbing medium, these studies involve number of variations on the nature and geometry of these components for making the results more refined. The present chapter reviews some of the attempts related to the photon attenuation measurements on elemental and compound substances using radioactive sources, secondary excited photons, parametric X-rays, discrete photons and proton induced X-ray emission (PIXE). Works already done around K-absorption edge, invoking mixture rule are also discussed. The photoeffect cross section $\sigma$ being an important parameter in the low energy region, some of the related works on anomalous scattering factors are also reviewed.
2.2 Attenuation and Cross section measurements - Early days

Low-energy photons are used in basic as well as applied sciences. These applications span from computerized tomography to transmission/reflection experiments for studying composition of ancient coins in archaeometry. All these applications of X-rays require an accurate knowledge of the probabilities of various interactions of photons with matter. For this purpose, the available data of mass attenuation coefficients are normally used. Experimental measurements of the mass attenuation coefficients have been performed since the early days of X-ray studies and an almost complete collection, including also a comparison with theoretical predictions was reported by several authors, not least of which are the references; Storm and Israel [1], Hubbell [2], Henke et al. [3] and Saloman et al. [4].

Data on the scattering and absorption of photons (X-rays and gamma rays) are required for many scientific, engineering and medical applications. Available tables usually include cross sections for selected elements and possibly a limited number of compounds and mixtures. A convenient alternative to manual calculations, using tabulated data, is to generate cross sections and attenuation coefficients for elements, compounds and mixtures as needed, using a computer. For this purpose, Berger and Hubbell [5] developed a computer program, called XCOM, and a database which can be used to calculate cross sections and attenuation coefficients for any element, compound or mixture. It covers photon energies from 1 keV to 100 GeV, atomic numbers from 1 to 94 and edge positions, jumps and scattering coefficients, but no shell and subshell cross-sections. Gerward et al. [6] have developed a Windows version of XCOM called WinXCOM. Orlic et al. [7] have developed an interactive MS Windows based computer program for generating, printing and displaying mass attenuation coefficients.

The National Bureau of Standards (NBS) database provide experimental X-ray attenuation coefficients (total absorption cross sections) and cross sections,
calculated using a relativistic Hartree-Slater model for the photoelectric cross section for all elements of atomic number \( Z = 1-92 \) for the energy ranges 0.1-100 keV [8]. They have displayed the information in both tabular and graphical form. The X-ray mass attenuation coefficients of Veigele [9] have been parameterized by Braziewicz et al. [10] in the photon energy range of 1-150 keV for all elements from hydrogen to plutonium \((Z = 1-94)\), taking into account the K-, M- and N-shell absorption edge structure existing in this energy interval. Hubbell has also compiled mass attenuation coefficients \((\mu/\rho)\) and mass energy-absorption coefficients \((\mu_n/\rho)\) and tabulated these quantities in units of \(m^2kg^{-1}\) for photon energies 1 keV to 20 MeV for 40 elements ranging from hydrogen \((Z = 1)\) to uranium \((Z = 92)\). In addition, these parameters are tabulated over this same energy range for 45 mixtures and compounds of dosimetric interest, computed from the above data using fractions-by-weight of the constituent elements. A bibliography of 290 references containing measured absolute-value photon total cross-section data above 10 eV is presented, by the same author. An index by element \((Z = 1\) to \(Z = 94)\) and energy range, characterizing experiments according to source, detector, and number of data points, is also included [11].

Gamma ray interaction studies at energies near the photoelectric absorption edges have been of interest to investigators in the field for quite some time now [12, 13]. The energy region near the photoelectric absorption edge in elements is interesting for many reasons. One reason is the validity of the mixture rule (referred to above) for the attenuation coefficients at energies close to the absorption edges [14]. This rule is valid when the effects on the atomic wave functions of the molecular bonding and chemical or crystalline environment are negligible. The attenuation coefficient values are believed to be affected by chemical, molecular and thermal environments. These phenomena lead to deviations of observed \((\mu/\rho)\) values from theoretical ones.

The measurements on attenuation of photons carried out in the present work are done around the K-edge of elements. In order to study the X-ray interaction processes near the absorption edges, one requires several radiation energies
around the edge energy.

There are five different techniques to obtain the required X-ray energies. They are:

I. Methods involving discrete energy radiations
a) Method using radioactive sources
b) Using secondary X-rays excited from elemental targets by photons from radioactive sources
c) Using secondary X-rays excited from elemental targets by the Proton Induced X-ray Emission (PIXE) Technique

II. Methods involving continuously variable energy radiations
d) By Compton scattering from a suitable target
e) Using Parametric X-ray Emission technique

The works already taken place with the techniques mentioned above are reviewed in the forthcoming section.

### 2.3 Methods involving discrete energy radiations

#### 2.3.1 Methods using radioactive sources

The most straightforward method is to use different radioactive sources which provide discrete X-ray energies, namely the characteristic X-rays of the daughter isotopes. However, availability of such sources is limited. The intensities of X-rays available from such sources also are comparatively low for scattering studies and photoelectric measurements, though they may be sufficient for attenuation measurements. Recently in our laboratory we had carried out investigations [15] on the attenuation coefficients and photoelectric effect on rare earth elements using $^{241}$Am gamma rays. Appaji Gowda et al. [16, 17] have determined the attenuation coefficients for tantalum, mercury and lead at energies between 24.14 and 136 keV and for several rare earth elements at energies between 6.4 and 84.3
keV, with a view to evaluate the anomalous scattering factors. Budak et al. [18] have measured the total attenuation coefficient in the range $40 \leq Z \leq 52$ using $^{241}\text{Am}$ gamma rays.

Angelone et al. [19] have measured the mass attenuation coefficient for elemental materials in atomic range $6 \leq Z \leq 82$ using X-rays from 13 up to 50 keV. Alam et al. [20] have measured 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. Cross sections for total atomic attenuation, total atomic photoelectric and total atomic scattering in nine elements $58 \leq Z \leq 68$ at 59.537 keV are also reported by Karabult [21].

Midgley has measured the X-ray linear attenuation coefficient for materials containing elements hydrogen to calcium [22]. As it is inconvenient to use elements like hydrogen, carbon and oxygen in pure forms for measurement of their gamma mass attenuation coefficients, the measurements are to be done indirectly, by using compounds of the elements or a mixture of them. Teli et al [23] gave a simple method of measuring the total mass attenuation coefficients $(\mu/\rho)$ of the elements in a compound simultaneously and in a single experiment through the measurements of the $(\mu/\rho)$ values of the concerned compounds and using the mixture rule. The method is applied for the measurement of $(\mu/\rho)$ of hydrogen, carbon and oxygen by using acetone, ethanol and 1-propanol.

A simple relation between the total photoeffect cross section of an element and the total attenuation cross section of its compound has been derived by Umesh et al [24]. Total attenuation cross sections of some 15 simple compounds have been measured by performing transmission experiments in a good geometry set up. Using these values, they have determined total photoeffect cross sections of elements of $Z \geq 47$ at 514.0, 661.6, 1115.5, 1173.2 and 1332.5 keV gamma ray energies and compared with Scofield’s theoretical cross sections. Accurate measurements on total attenuation coefficients for gamma rays was utilised by Govinda Nayak et al [25] to find effective atomic numbers ($Z_{eff}$) for the photoelectric process at 59.54 keV of three polymers, an alloy, a compound and an
2.3.2 Using secondary X-rays excited from elemental targets by photons from radioactive sources

The second technique for obtaining the energies around the absorption edge is by secondary excitation of X-rays from targets using primary photons from radioactive sources. In this method, the incident photons excite the inner shells of the secondary excitation target and the subsequent decay of the excited atom results in the emission of the characteristic X-rays. The same qualitative arguments mentioned for the first method are applicable also for this technique.

Several authors recently reported the mass attenuation coefficients of elements around K-edge in various low energy ranges using $^{241}$Am source and different targets. The K-absorption edge of some rare earth elements have been investigated by Mallikarjuna et al. [26]. X-ray attenuation coefficients of Cu, In and Se at various energies in the range $11.9 - 37.3$ keV were investigated by Cevika et al. [27]. The mass attenuation coefficients of Ag, Cs, Ba and La in the region $25 - 40$ keV using energy dispersive X-ray flourescence (EDXRF) were measured by Polat et al. [28]. The same technique was adopted by Necati Kaya et al. [29] to find the K-shell absorption jump factors and jump ratios for Tm, Yb, Lu, Hf, Ta, W, Re and Os in the energy region $56 - 77$ keV. Turgut et al. [14] have also determined the total mass attenuation coefficients for Co and some compounds of Co and Mn at different energies between $4.508$ and $11.210$ keV using secondary excitation method.

The total atomic attenuation, total atomic photoelectric and total atomic scattering cross sections by measuring the transmission factor has been fairly accurately calculated by Budak et al [18]. K X-ray fluorescence (XRF) spectra were also measured for Zr, Nb, Mo, Ag, In, Sn and Te at excitation energy of $59.54$ keV. The method of secondary excitation has been used by Midgley et al. and Turgut et al. [30] to find the total mass attenuation coefficients for element Fe and compounds FeF$_3$, Fe$_2$O$_3$, FeCl$_2$.4H$_2$O, FeCl$_3$.2NH$_4$Cl.H$_2$O at different en-
ergies in the 4.508-17.443 keV range. 59.5 keV gamma rays emitted from an

\(^{241}\text{Am}\) annular source was used to excite secondary exciters of Ti, V, Cr, Ni, Cu, 
Zn, As, Se, Br, Rb, Sr, Y, Zr, Nb and Mo. They have observed that mixture 
rule method is not a suitable method for determination of the mass attenuation 
coefficients of compounds, especially at energy that is near the absorption edge. 

Ugur Cevika et al [27] has measured the X-rays attenuation coefficients for 
Cu, In and Se in elemental state and the semiconductor CuInSe\(_2\) at 15 different 
energies from 11.9 to 37.3 keV by using the secondary excitation method. Mono-
chromatic photons were obtained using the secondary targets: Br, Sr, Mo, Cd, 
Te and Ba. 59.54 keV gamma rays emitted from an annular \(^{241}\text{Am}\) radioactive 
source were used to excite secondary X-rays from these targets. Polat et al [28] 
have derived the K-shell absorption jump factors from mass attenuation coeffi-
cients measured using energy dispersive X-ray fluorescence for samples in the 
form of the compounds \(\text{Ag}_2\text{O}_3\), \(\text{CsHCO}_3\), \(\text{Ba(OH)}_2\) and \(\text{La}_2\text{O}_3\). These measure-
ments, in the region 25-40 keV, were done in a transmission geometry utilizing 
the K X-rays from different secondary targets Sb, Pr, Nd and Sm excited by the 
59.5 keV photons from an \(^{241}\text{Am}\) annular primary source. 

Necati Kaya et al. [29] have derived the K-shell absorption jump factors and 
jump ratios from new mass attenuation coefficient data measured using an en-
ergy dispersive X-ray fluorescence (EDXRF) spectrometer for Tm, Yb elements 
using \(\text{Tm}_2\text{O}_3\), \(\text{Yb}_2\text{O}_3\) compounds and pure Lu, Hf, Ta, W, Re and Os. The 
measurements, in the region 56 - 77 keV, were done in a transmission geometry utilizing 
the \(\text{K}_{\alpha 1}\), \(\text{K}_{\alpha 2}\), \(\text{K}_{\beta 1}\) and \(\text{K}_{\beta 2}\) X-rays from different secondary targets 
Yb, Ta, Os, W, Re and Ir, etc. excited by the 123.6 keV photons from an \(^{57}\text{Co}\) annular source. 

Gowda and Powers [31] used \(\text{K}_\alpha\) and \(\text{L}_\alpha\) X-ray lines produced by heavy 
ion interaction with thick targets of different materials as the source. Gopal and 
Sanjeeviah [32] have demonstrated the effect of multiple scattering for \(\mu t\) varying 
up to 4.2 for 84 and 661.6 keV gamma rays using carbon and lead absorbers. In 
their experiment using sodium iodide detector, they observed a deterioration of
the resolution of the detector as the absorber thickness increases above $1/\mu$, with a simultaneous increase in the value of the measured attenuation coefficient.

### 2.3.3 Using secondary X-rays excited from elemental targets by the Proton Induced X-ray Emission (PIXE) Technique

Proton Induced X-ray Emission (PIXE) is another versatile method [33] which utilizes the secondary excitation from targets. Here, protons are used instead of photons for secondary X-ray production. Rapid advances made in the analytical methods using X-rays make it possible for accurate measurements of values of X-ray attenuation coefficients which give important information about the composition of materials.

The technique has two definite advantages over the photon induced X-ray production method. First of all, the incident flux of protons (accelerated in a particle accelerator) is much larger than the number of incident photons available from radioactive sources. Consequently, the flux of secondary X-rays will be much larger and the statistical accuracy is correspondingly increased. Also, the background is relatively less in the PIXE spectrum. However, reported investigations on X-ray interactions using the PIXE technique are rather limited.

Varier et al. [34] have reported attenuation coefficients of copper, tantalum and lead targets using the technique of PIXE in the energy region $7 - 15$ keV. Pansky et al. [35] have used a new technique for studying Fano factor and the mean energy per ion pair in gases using low energy X-rays generated by the PIXE technique. A different method for measuring the thickness of aluminum foils used as X-ray absorbers in thick-target PIXE analysis using the change in $K_\beta/K_\alpha$ X-ray intensity is described by Campbell et al. [36]. Braziewicz et al. [37] have parameterized mass attenuation coefficients using a simple analytical representation of all elements between hydrogen and plutonium. Karydas [38] have carried out measurements on Resonant Raman Spectroscopy (RRS) using
vanadium $K_{\alpha}$ X-rays. Under favourable conditions, the PIXE method of X-ray production is superior to the photon induced X-ray generation as a source of the X-radiations for the interaction studies. This is so, especially because of the comparatively lower background in the PIXE spectra.

2.4 Methods involving continuously variable energy radiations

2.4.1 By Compton scattering from a suitable target

All the three techniques mentioned above suffer from one common disadvantage, namely, that the available gamma energies are discrete. Continuously variable energy can be made available by the use of Compton scattering of the primary photons from radioactive sources. It is known that the energy of the Compton scattered photons depends both on the energy of the primary photons and on the angle of scattering. In a practical situation the scattered energy can be easily varied over a reasonably large range by varying the angle of scattering in the range from about $30^\circ$ to $160^\circ$. For example, in the case of 59.54 keV gamma rays from $^{241}\text{Am}$ source, the available Compton energies cover the range from 48.56 keV to 58.62 keV. However, the Compton scattering method also requires strong primary photon sources. Also, the scattered radiation will not be strictly monochromatic: it is subject to an energy spread decided by the spread in the scattering angles arising from finite dimensions of the source and target. Budak and Polat [39] and Polat et al. [40] have applied this technique for the measurement of the K-shell absorption jump factors and jump ratios in some rare earth elements (Gd, Dy, Ho and Er) in the energy range 48 – 59 keV from attenuation measurements near the absorption edge energies. They have used Aluminium as the secondary exciter.
2.4.2 Using Parametric X-ray Emission technique

An entirely new technique was developed recently by Tamura et al. [41] to measure mass attenuation coefficients around the K-edge for elements Zr, Nb and Mo. Their technique involves the emission of X-rays around the Bragg angle when relativistic electrons are incident on a crystal plate like silicon. This process has been called the Parametric X-ray Radiation (PXR). The X-rays generated by this technique are highly monochromatic, have continuously variable energy and are directed and coherent.

2.4.3 Tunable X-ray source

Yet another method, recently utilized for attenuation measurements is using tunable X-ray sources. The X-ray attenuation coefficients of bismuth and of uranium were measured in the regions of 40 - 240 and 70 - 240 keV, respectively, using a tuneable hard X-ray source based on the linear electron accelerator at the University of Ghent by Maternaa et al [42]. A low energy range (120 keV) tunable monochromatic X-ray source for metrological studies is described by Marie-Christine et al [43]. They have used the set-up to find the attenuation coefficients in the 410 keV energy range. The results for aluminum and copper with average relative uncertainties of 1% and 3% respectively.

2.5 Multiple scattering effects and the criterion

$(\mu t \leq 1)$

In general, for experiments aimed at the determination of attenuation coefficients, the total absorber thickness used is less than one mean free path (given by $1/\mu$). This is referred to as the $\mu t \leq 1$ criterion. It is used to ensure that multiple scattering effects are negligible. Gopal and Sanjeeviah [32] have demonstrated the effect of multiple scattering for $t$ varying up to 4.2 for 84 and 661.6 keV gamma rays using carbon and lead absorbers. In their experiment using sodium
iodide detector, they observed a deterioration of the resolution of the detector as the absorber thickness increases above \((1/\mu)\), with a simultaneous increase in the value of the measured attenuation coefficient. Therefore Gopal and Sanjeeviah had stressed this criterion in their work with 84 and 661.6 keV gamma rays using carbon and lead absorbers.

The effect of multiple scattering on the pulse height distribution of the transmitted gamma rays and on the measured attenuation coefficients was studied and shown to be small up to three mean free paths by Kane et al. [44]. Values of attenuation coefficients were determined in the case of lead for 0.662 MeV, 1.116 MeV, 1.17 MeV and 1.33 MeV gamma rays, and in the case of tantalum and molybdenum for 0.662 MeV and 1.116 MeV gamma rays.

Varier and Kunju [45] conducted a study of the effect of transverse dimensions, that is, in a direction perpendicular to the direction of the incident beam. They concluded that for small transverse dimensions, absorber thickness up to even four mean paths does not significantly contribute to multiple scattering. For larger transverse dimensions, multiple scattering is important and could affect the measured attenuation coefficient for absorber thickness above one mean free path. The criterion \((\mu t \leq 1)\) could also apply for transverse dimensions also.

### 2.6 Studies specifically focussed on absorption edges

If the photon energy is high enough, the photoabsorption spectrum comprises the characteristic edges (K, L, M etc.,) corresponding to the binding energies at which absorption coefficient jumps to higher values. Photon attenuation measurements around the edges gain importance because of this phenomena and there have been several attempts to make the measurements around these edges, especially around K-edge.

Near K-edge linear attenuation coefficients for stoichiometric crystalline and amorphous gallium arsenide were derived from total electron yield photocurrent
measurements by Owens et al. [46]. Their measurements show considerable near-edge structure when compared to curves generated from standard atomic data tables. However, very little difference is found between the crystalline and amorphous samples, suggesting that the bulk of the structure arises from the local coordination environment. Mallikarjuna et al. [26] have measured the total attenuation cross sections of rare-earth elements in a narrow beam good geometry using a high-resolution hyper pure germanium detector in the energy range 6 – 85 keV. The data have been used to derive the K-shell photoeffect cross sections at the K-edge, the oscillator strength and the K-jump ratio of the elements La, Ce, Pr, Nd, Sm, Gd, Dy, Ho and Er.

The K-shell fluorescence yield, fluorescence cross-section and ratio between the radiative transition width and the Auger transition width have been measured for medium-Z elements, 30 ≤ Z ≤ 50, using a geometrical configuration method by Gudennavar [47]. They have also measured the K-shell fluorescence cross section or K X-ray production cross section, the K-shell fluorescence yield, and the ratio between the widths of the radiative transition and the Auger transition, for some high-Z elements 62 ≤ Z ≤ 82 [48].

Murty et al. [49] have determined total photon cross sections around the K edges of four elements Cu, Sn, Pb and U using a Ge(Li) detector, and argon and krypton proportional counters on a 'good geometry' set-up. The total photoelectric cross sections are extracted by subtracting the small scattering contribution from the total photon cross sections. They have also evaluated total-to-K-shell photoelectric cross section ratios (K-jump ratios) by extrapolating the total photon cross section data to the K-edge.

Photoelectric interaction below the K edge were studied by Reddy et al. [50] using the transmission method in the heavy elements U, Th, Pb, and Au at energies 30.9, 35.9, and 55.4 keV. The photoelectric cross sections, obtained by subtracting the small scattering contributions from the total cross section, are compared with theoretical predictions of Scofield [51] and of Storm and Israel [1]. General agreement is obtained, except for U and Th at 30.9 keV where their
experimental values show a slight preference to the calculations of Storm and Israel rather than the theoretical ones used by Scofield.

2.7 Studies related to mixture rule

In the description of photon attenuation by mixtures of elements, it is a standard practice to assume that the contribution of each element to the attenuation is additive. This assumption yields the well-known mixture rule [52] which gives the attenuation coefficient of any substance as the sum of the appropriately weighted contributions from the individual atoms. The mixture rule is valid when the effects on the atomic wave function of molecular bonding and chemical or crystalline environment are negligible. These values are also believed to be affected by the chemical, molecular and thermal environments. This is because of the existence of fine structure above the edge. These phenomena lead to the deviation of the experimental $(\mu/\rho)$ values from that of the theoretical values, since the calculation of the theoretical value has been done by considering the cross-section for an isolated atom. This deviation is termed as the breakdown or the non-validity of the mixture rule.

Turgut et al [30] have studied X-ray attenuation coefficients at different energies and the validity of the mixture rule for the elements Co, Mn, and compounds Co$_2$O$_2$, CoCl$_3$.6H$_2$O, CoSO$_4$.7H$_2$O, MnCO$_3$, KmnO$_4$, MnCl$_2$.2H$_2$O, MnCl$_2$.4H$_2$O at different energies between 4.508 and 11.210 keV using a secondary excitation method. Ti, Co, Ni, Cu, Zn, As, Se were chosen as secondary exciter. Gamma rays (59.54 keV) emitted from an $^{241}$Am annular source were used to excite a secondary exciter. They have shown that for a given incident photon energy the mixture rule breaks down not only for the compounds which contain an element whose K-edge energy is less than the photon energy, by as much as approximately 1500 eV, but also for those for those with K-edge energy slightly more than the photon energy by approximately 100 eV. In other words, the mixture rule breaks down for photon energies ranging from about 100 eV below the K-edge to about
1500 eV above K-edge.

Very few measurements have been made on the non-validity of the mixture rule. In the case of measurements near the bromine K-edge, the results showed that the mixture rule breaks down for incident photon energies within 1 keV above the edge [53, 54]. Jackson [55] pointed out that the range of validity of the mixture rule is not established close to the absorption edge. Nagel [56] had also pointed out, while discussing the absorption edge effects in electron probe microanalysis, that the tabulated values can be in error by 50% near an edge and by 10% up to 400 eV above the edge. Hubbell et al. [57] estimated the magnitude of the discrepancy between theoretical and experimental K-edge cross-sections for the elements from Ti to Zn to be in the range from 3% to 12%. However, Govinda Nayak [58] asserts that the mixture rule can be used with confidence to evaluate attenuation coefficients in polymers also, as in the case of compounds and alloys. Effective atomic numbers ($Z_{eff}$) of three polymers, an alloy, a compound and an element have been determined for photoelectric process at 59.54 keV from the accurately measured total attenuation coefficients, for $\gamma$ ray attenuation. Possible conclusions are drawn on electron binding effects and K-edge effects.

A method to determine the K-shell photo effect cross sections of some compounds of the rare earth elements La, Ce, Pr, Nd, Sm, Gd, Dy, Ho and Er have been developed a new method, for energies above the K-edge of these elements, by Mallikarjuna et al. [26]. In this method, the K-shell photoeffect cross sections of rare earth elements at energies above the K-shell threshold are obtained by using log-log plot of the experimentally measured total attenuation cross sections of their simple compounds. The method does not require any knowledge of the contributions of other competing processes. A simple formula has been obtained by studying the variation of the K-shell photoeffect cross sections versus E and Z. This formula provides for an easy and rapid evaluation of the K-shell photoeffect cross sections for any element with $57 \leq Z \leq 68$ and for energies up to 84.3 keV.
2.8 Studies on anomalous scattering factors

The anomalous scattering factor (ASF) of X-ray resonant scattering changes remarkably near an absorption edge of an atom. It is well known that this change is significant for the phase determination of crystal structure factor and the study of X-ray magnetic scattering. ASF ($f' + if''$), near the absorption edge is so sensitive to the conduction band structure and the lifetime of intermediate transition process that it is not easy to evaluate it theoretically. Thus, it is interesting to investigate the consistency between the calculated ASF and the measured one. This process has been extensively studied theoretically as well as experimentally in view of its importance in some nuclear-physics, radiation-shielding, and astrophysical problems.

Chantler [59] addresses key discrepancies and derives theoretical results in near-edge soft X-ray regions. Reliable knowledge of the complex X-ray form factor and the photoelectric attenuation coefficient is required for crystallography, medical diagnosis, radiation safety and XAFS studies. This work brings out new theoretical investigation in resolving discrepancies of atomic form factors and attenuation coefficients in the near-edge soft X-ray regime. Cromer and Liberman [60] have given extensive tabulations of dispersion corrections over a range of wavelengths commonly used by crystallographers. Kissel et al [61] have developed a computer program based on the second order S-matrix formalism to predict the total atom Rayleigh scattering amplitudes. Kissel and Pratt [63] have tabulated the values of the high-energy limit, based on the S-matrix calculations, to be added to $f'$ and also given the values of correction to be added to the Cromer-Liberman $f'$ values. Bin Zhoua et al [62] proposes simple computational schemes to calculate the anomalous scattering factors $g'$ and $g''$ for ions, which utilize only the subshell photoionization cross sections of neutral atoms and ionic edge positions, without any ionic photoionization cross sections. Recently, Cullen et al [64] have provided a photon data library (EPDL97) that includes photon interaction data for all elements with atomic number between 1 and 100 over the range 1 eV to 100 GeV. D. V. Rao et al [65] measured the elastic scattering cross
sections for Pt, Au and Pb in the energy region $5.41 \leq E \leq 9.23$ keV. They have also developed a new method to estimate the degree of monochromaticity, geometrical effects of the measuring system, solid angle correction and some considerations which are necessary in experiments using X-ray tube with secondary target arrangement. Henke et al [66] have given tabulations of the dispersion corrections calculated for all Z in the energy range 30 eV to 30 keV, based on a semi-empirical approach using theoretical experimental attenuation coefficient data base.

On the experimental side, it can be noticed that two types of techniques have been mainly employed to determine the values of $f'$ and $f''$. These are: (1) direct method and (2) attenuation coefficient method. Direct method has been employed by several investigators [67, 68, 69, 70] to calculate $f'$ and $f''$. Appaji Gowda et al [17] derives the dispersion corrections to the forward Rayleigh scattering amplitudes of tantalum, mercury and lead derived using photon interaction cross sections. The same authors have also determined the anomolous scattering factors of some rare earth elements La, Ce, Pr, Nd, Sm, Gd, Dy, Ho and Er [16] for the energy region from 6 to 85 keV. They have used Scofield’s [51] photoeffect cross-sections compiled in XCOM program, below 6 keV.
References


