Chapter-4

Measurement of $L_{III}$ subshell absorption edge jump ratio

$(r_{III})$ and jump factor $(J_{III})$

4.1 Introduction

In this Chapter, measurements of $L_{III}$ subshell absorption edge jump ratios $(r_{III})$ and jump factors $(J_{III})$ of W, Au, Hg and Pb by using EDXRF technique are presented in detail. Comparison of the measured values with theoretically calculated values of the jump ratio $(r_{III})$ and jump factor $(J_{III})$ as well as the associated parameters needed for their determination are given in subsequent sections.

A plot of $L_{III}$ subshell photo effect cross-section as a function of photon energy for a given target gives a saw-tooth structure around the $L_{III}$ subshell edge. The upper energy branch corresponds to photoelectric cross-section due to the $L_{III}$ subshell, M and higher shells and the lower energy branch corresponds to M and higher shells. Therefore, the ratio of the photoelectric cross-section of the upper energy branch to that of the lower energy branch gives the $L_{III}$ subshell absorption jump ratio. Similarly absorption jump factor is associated with photoelectric absorption coefficient $\tau$ for different shells/subshells (i.e. $\tau_K, \tau_{LI}, \tau_{LII} \ldots$) and is defined as the fraction of the total

Part of this work has been published in


absorption that is associated with a given subshell rather than for any other shells.

For example, $L_{\text{III}}$ shell jump ratio $r_{L_{\text{III}}}$ is given as

\[
r_{L_{\text{III}}} \approx \frac{\tau_{L_{\text{III}}} + (\tau_{M_{\text{I}}} + \tau_{M_{\text{II}}} + \tau_{M_{\text{III}}} + \ldots) + \ldots}{(\tau_{L_{\text{I}}} + \tau_{M_{\text{I}}} + \tau_{M_{\text{II}}} + \ldots) + (\tau_{N_{\text{I}}} + \tau_{N_{\text{II}}} + \tau_{N_{\text{III}}} + \tau_{N_{\text{IV}}} + \ldots)}
\]  

(4.1)

Similarly, $L_{\text{III}}$ shell absorption jump factor $J_{L_{\text{III}}}$ is given as

\[
J_{L_{\text{III}}} = \frac{\tau_{L_{\text{III}}}}{\tau_{L_{\text{III}}} + (\tau_{M_{\text{I}}} + \tau_{M_{\text{II}}} + \tau_{M_{\text{III}}} + \ldots) + (\tau_{N_{\text{I}}} + \tau_{N_{\text{II}}} + \tau_{N_{\text{III}}} + \tau_{N_{\text{IV}}} + \ldots)}
\]  

(4.2)

where $\tau_i$ is photoelectric cross-section of $i$th shell/subshell.

Recently Kaya et al. (2008) has measured $L_{\text{III}}$ subshell absorption jump ratio and jump factor for bismuth by measuring mass attenuation coefficient values using nineteen different elements whose K’s and L’s energies lies on both side of $L_{\text{III}}$ subshell absorption edge of Bismuth. He has measured mass attenuation coefficient at 36 energies in order to deduce the value of $L_{\text{III}}$ subshell absorption jump ratio. Clearly this method is expensive, exhaustive and requires many monoenergetic gamma sources or many thin foils. Thus keeping in mind, the limitations of above used method, $L_{\text{III}}$ subshell absorption jump ratio and jump factor of W, Hg, Au and Pb has been measured employing an alternative technique to fulfill the following objectives:

- to evolve an experimental technique for measuring of $L_{\text{III}}$ subshell absorption edge jump ratio and jump factor which would be less expensive, less time consuming and works more efficiently.
- to provide experimental data relevant to $L_{\text{III}}$ subshell edge jump ratio and jump factor for above said high Z elements, where no experimental data except for Bismuth (Kaya et al. 2008) is available in literature.

EDXRF method involve the determination of $L_{\text{III}}$ subshell jump ratio and jump factor from the measured values of LIII subshell X-ray production cross-section, total $L_{\text{III}}$ subshell atomic cross-section and calculated value of $L_{\text{III}}$ subshell fluorescent yield.
The values of L_{III} subshell X-ray production cross-section ($\sigma_{x_{III}}$) has been determined from the experimentally measured values of L_{i} shell X-ray production cross-section $\sigma_{x_{i}}$ (i = $\ell$, $\alpha$, $\beta$, and $\gamma$) by subtracting the contribution due to L_{I} and L_{II} subshell cross-sections. Where as, the values of total L_{III} subshell atomic cross-section were obtained from the experimentally measured values of total atomic cross-section ($\sigma_{x}$) by subtracting the contribution of scattering and K, L_{I} and L_{II} shell/subshell photoionization cross-sections. Detail description of the method of measurement has been given in subsequent paragraphs.

4.2 Method of computation and measurement

4.2.1 Measurement of L_{III} subshell absorption edge jump factor ($J_{L_{III}}$)

L_{III}-subshell jump factor of an element has been measured using the following relation

$$J_{L_{III}} = \frac{\sigma_{x_{III}}}{\sigma_{t_{III}} \omega_{3}}$$

(4.3)

where $\sigma_{x_{III}}$ represent L_{III} subshell X-ray production cross-section , $\sigma_{t_{III}}$ represent total photo ionization cross-section of L_{III} and higher subshells and $\omega_{3}$ represent L_{III} subshell fluorescence yield.

4.2.2 Measurement of L_{III} subshell X-ray production cross-section ($\sigma_{x_{III}}$)

L shell X-ray emission spectrum is relatively more complex than that of the K X-ray, the investigations relating to the L X-ray spectrum is the simultaneous presence of X-rays characteristic of all the three subshells in some of the L X-ray groups. The
separation between the L subshell edges is very small and is comparable to that of the binding energies of the outer shell electrons that jump to fill the L shell vacancies’ resulting in the emission of X-ray. Consequently several L X-rays lines of closely spaced energies fall under one photo peak and are not fully resolved even with the presently available best resolution energy dispersive spectrometers. Within the present limit of resolution of the energy dispersive spectrometers, L X-ray spectra can be resolved into four main groups L\(_l\), L\(_\alpha\), L\(_\beta\) and L\(_\gamma\) in most of the high Z elements. Out of these four peaks, L\(_l\) and L\(_\alpha\) originate purely from the transitions to L\(_{III}\) subshell with J=3/2, whereas L\(_\beta\) peak of X-rays contains contributions from all the three subshells of L shell. However L\(_\gamma\) X-ray peak contains only the contribution from L\(_1\) and L\(_2\) (J=1/2) subshell and has been rejected. Thus the author has measured the X-ray production cross-sections for L\(_l\), L\(_\alpha\) and L\(_\beta\) groups of L X-ray lines in different elements in the range 74≤Z≤82.

Details of the experimental setup used for the present measurements of L\(_l\), L\(_\alpha\) and L\(_\beta\) partial X-ray production cross-sections is same as given in section 3.2. In present investigation, self supporting target of Hg made from its stable chemical compound HgCl\(_2\) using the technique described elsewhere (Tirasoglu, 2006) and metallic targets of W, Au and Pb has been used. All the targets were procured from Sigma-Aldrich and were 99.999 % pure as quoted by manufacturer. It is evident from the spectrum of W (figure 4.1) that all the L X-ray lines present in the spectrum are not fully resolved from each other due to limited resolution of the spectrometer, instead they appear as four distinct groups of lines corresponding to L\(_l\), L\(_\alpha\), L\(_\beta\) and L\(_\gamma\) groups. But out of these four major peaks, only three peaks L\(_l\), L\(_\alpha\) and L\(_\beta\) were used for the present investigations. The natural background counts were also recorded for equal time. This was done by removing 241Am source from its original position. This
background was subtracted from the L X-ray spectrum recorded with 59.54 keV gamma rays incident upon the target. The experiment with each target was run for a sufficiently long time to achieve statistical uncertainty ~2% in the counts under $L_\ell$ peak of all elements. In other L X-ray peaks ($L_\alpha$ and $L_\beta$) the statistical uncertainty in the counts were ~1%.

From the elementary considerations as discussed in section 3.3.1, the number of L X-ray, $N_{Li} (i=\ell, \alpha$ and $\beta$), counted per unit time under the peak $L_i$ using energy dispersive X-ray spectrometer is given as:

$$N_{Li} = S\alpha \frac{\omega_1 \omega_2}{(4\pi)^2} \frac{N_a}{M} \sigma_{Li}^{X} \epsilon_{Li}, t \beta_{Li}$$

where $S$= the number of gamma rays emitted from the source per unit time.

$\omega_1$ = solid angle subtended by source on target.

$\omega_2$ = solid angle subtended by target on detector.

$\alpha$ = the correction factor which takes into accounts, the absorption of gamma rays in the source and the target

$\frac{N_a}{M}$ = number of atoms per gm of the target material.

t = thickness of target in gm/cm$^2$

$\beta_{Li}$ = the correction factor which takes into account the effect of absorption of incident gamma rays and emitted $L_i$ group of L X-rays in the target.

$\sigma_{Li}^{X}$ = the cross-section for the production of $L_i$ group of L X-rays at the incident gamma ray energy.

$\epsilon_{Li}$ = the Si(Li) detector photo peak detection efficiency for $L_i$ group of L X-rays emitted from the target.
Re-writing expression (4.4), we get

\[ \sigma_{Li}^X = \frac{N_{Li} M}{t \beta_{Li} \left[ \frac{S \alpha \omega \omega_{Li} e_{Li} N_{a}}{(4\pi)^2} \right]} \]  

(4.5)

Where \( i = \ell, \alpha \) and \( \beta \)

It is clear from the expression (4.5) that the partial L\(_i\) subshell X-ray production cross-section can be determined from the equation using the measured values of \( N_{Li} \), the geometrical efficiency factor \( \frac{S \alpha \omega \omega_{Li} e_{Li} N_{a}}{(4\pi)^2} \) and the calculated values of the target self absorption correction factor, target thickness and mass of the target element.

### 4.2.2.1 Measurement of \( (N_{Li}) \)

Targets of elements W, Au, Hg and Pb were irradiated with 59.54 keV gamma rays and the L X-ray spectra were recorded in each case. From these spectra, the counting rates, \( N_{Li} \), under the different L X-ray peaks i.e. \( L_\ell, L_\alpha \) and \( L_\beta \) etc. were noted. Typical spectra of W and Pb target elements have been given in figure 4.1 and 4.2 respectively.

### 4.2.2.2 Determination of self-absorption correction factor \( (\beta_{Li}) \)

The targets of elements under investigation were not infinitely thin. As a result, these targets absorb a fraction of the incident gamma rays before interaction with the atoms of target elements and fraction of emitted L X-rays before they came out of the target for detection. The correction for this absorption amounts to replacing the target of thickness ‘t’ by a target of effective thickness \( t_{eff} = t\beta \), where ‘\( \beta \)’ is the correction factor which takes into account the absorption of incident ray and emitted X-rays in the
Fig. 4.1: L X-ray Spectrum of W representing $L_i$, $L_\alpha$, $L_\beta$ and $L_\gamma$ peaks recorded with Si(Li) detector irradiated with 59.54 keV photon.
Fig. 4.2: L X-ray Spectrum of Pb representing $L_\alpha$, $L_\beta$, $L_\gamma$ and $L_\delta$ peaks recorded with Si(Li) detector irradiated with 59.54 keV photon.
target and is known as self–absorption correction factor as discussed in section 3.3.1.

Following expression has been used for evaluating $\beta_{Li}$:

$$
\beta_{Li} = \frac{1 - \exp[-(\mu_p + \mu_{Li})t / \cos \theta]}{(\mu_p + \mu_{Li})t / \cos \theta}
$$

(4.6)

As $\theta = 45^0$ in present case, so expression (4.6) can be rewritten as

$$
\beta_{Li} = \frac{1 - \exp[-(\mu_p + \mu_{Li})\sqrt{2t}]}{(\mu_p + \mu_{Li})\sqrt{2t}}
$$

(4.7)

where $\mu_p$ and $\mu_{Li}$ are absorption coefficients of target element at incident photon and weighted average energy of emitted $i^{th}$ group of $L_i$ X-ray. The self–absorption correction factor $\beta_{Li}$ for aforesaid target elements has been calculated using absorption coefficients from WinXCom (Gerward et al., 2001) computer code.

4.2.2.3 Determination of geometrical efficiency related factor

$$
\left( \frac{S_0 \omega \omega \frac{E_{Li}}{N_s}}{(4\pi)^2} \right)
$$

Value of factor $\frac{S_0 \omega \omega \frac{E_{Li}}{N_s}}{(4\pi)^2}$ in expression (4.5) which contains the terms related to flux of 59.54 keV gamma-ray emitted from source, geometrical factor, absolute efficiency of detector needed for the determination of $L_i$ X-ray production cross-section has been determined experimentally in a separate experiment. For this purpose some low $Z$ target elements with atomic number in the range $27 \leq Z \leq 42$ having same size as the experimental targets, have been so chosen that the K X-rays emitted from them lie in the energy region of the $L_i$ X-rays of the experimental targets. The experimental targets were replaced by the low $Z$ element targets and K X-rays emitted from them were counted by the same detector in the same experiment setup. The counts
For low Z targets, as measured by the detector under the photo peak is given:

\[ N_{Ki} = \frac{S_{\alpha_0 \alpha_2} N}{(4\pi)^2 M \sigma_{Ki}^{\nu} e_{Ki} t \beta_{Ki}} \]  

(4.8)

Various terms in this expression have the same meaning as in expression (4.4) but correspond to K X-rays of low Z elements.

Expression (4.8) can be rewritten as:

\[ \frac{S_{\alpha_0 \alpha_2} e_{Ki} N}{(4\pi)^2} = \frac{N_{Ki} M}{t \beta_{Ki} \sigma_{Ki}^{\nu}} \]  

(4.9)

The theoretical values of \( \sigma_{Ki}^{\nu} \) needed in expression (4.9) has been calculated using relation (3.27) by making use of the values of K-shell photo ionization cross-section \( \sigma_{\nu}^{p} \) tabulated by Scofield (1973), \( \omega_{k} \) the K shell fluorescence yield by Krause (1979), \( F_{ki} \) the fractional K \( i \) X-ray emission rates by Scofield (1974\( a \)). The values of \( N_{Ki} \) were determined by measuring the areas under the K \( i \) X-ray peaks in the spectrum taken with low Z targets. The energy of K \( i \) X-ray emitted by the low Z targets ranges between 7 keV to 17 keV.

The value of the factor \( \frac{N_{Ki} M}{t \beta_{K\alpha} - \sigma_{K\alpha}^{\nu}} \) against the K \( i \) X-ray energies (of these low Z target elements) has been plotted. A third degree polynomial fit was obtained from the plotted values. The value of this factor at energies of L \( i \) X-ray peak needed to determine the L \( i \) (i=\( l, \alpha, \beta \) and \( \gamma \)) subshell X-ray production cross-section of the elements under study were then read from the plot. Fitted values of factor \( \frac{S_{\alpha_0 \alpha_2} e_{Li} N_{Li}}{(4\pi)^2} \) generated from the fitted polynomial against L \( i \) X-ray energies of experimental targets have been given in Table 4.1.
Table 4.1: Values of factor $\frac{S_a \alpha \omega_{l} \omega_{\alpha} \varepsilon_{l,\alpha} N_a}{(4\pi)^2}$ for W, Au, Hg and Pb targets at $L_i$ (i= l, $\alpha$ and $\beta$) X-ray energies.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Element</th>
<th>$L_i$ X-ray group</th>
<th>Value of factor $\frac{S_a \alpha \omega_{l} \omega_{\alpha} \varepsilon_{l,\alpha} N_a}{(4\pi)^2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>W</td>
<td>$L_i$</td>
<td>2.04 x10$^7$</td>
</tr>
<tr>
<td></td>
<td>W</td>
<td>$L_{\alpha}$</td>
<td>2.22 x10$^7$</td>
</tr>
<tr>
<td></td>
<td>W</td>
<td>$L_{\beta}$</td>
<td>2.33 x10$^7$</td>
</tr>
<tr>
<td>2.</td>
<td>Au</td>
<td>$L_i$</td>
<td>2.23 x10$^7$</td>
</tr>
<tr>
<td></td>
<td>Au</td>
<td>$L_{\alpha}$</td>
<td>2.33 x10$^7$</td>
</tr>
<tr>
<td></td>
<td>Au</td>
<td>$L_{\beta}$</td>
<td>2.29 x10$^7$</td>
</tr>
<tr>
<td>3.</td>
<td>Hg</td>
<td>$L_i$</td>
<td>2.26 x10$^7$</td>
</tr>
<tr>
<td></td>
<td>Hg</td>
<td>$L_{\alpha}$</td>
<td>2.34 x10$^7$</td>
</tr>
<tr>
<td></td>
<td>Hg</td>
<td>$L_{\beta}$</td>
<td>2.25 x10$^7$</td>
</tr>
<tr>
<td>4.</td>
<td>Pb</td>
<td>$L_i$</td>
<td>2.30 x10$^7$</td>
</tr>
<tr>
<td></td>
<td>Pb</td>
<td>$L_{\alpha}$</td>
<td>2.34 x10$^7$</td>
</tr>
<tr>
<td></td>
<td>Pb</td>
<td>$L_{\beta}$</td>
<td>2.14 x10$^7$</td>
</tr>
</tbody>
</table>
4.3 Measurement of $L_{III}$ subshell photoionization cross-section ($\sigma_{a_{III}}$)

For this, first total atomic cross-section ($\sigma_t$) of incident gamma-rays in elements W, Au, Hg and Pb have been measured employing narrow beam transmission geometry as shown in figure 3.8. Incident ($I_o$) and transmitted beam intensity (I) for each sample were measured for sufficiently large fixed preset time so that the statistical uncertainty could be kept below 1%. Stability and reproducibility of the procedure has been tested before and after each run. Total atomic cross-section ($\sigma_t$) for these elements under examination has been calculated from the relation

$$\sigma_t = \frac{M}{N_a} \ln \left( \frac{I}{I_o} \right) \tag{4.10}$$

where ‘t’ is thickness of target element, M is atomic mass of target sample and $N_a$ is Avogadro’s number.

From the experimentally measured total atomic interaction cross-sections $\sigma_t$, contribution of scattering cross-section as well as K, L1 and L2 shell/subshell photoionization cross-section has been subtracted to obtain the value of $\sigma_{a_{III}}$.

Measured values of $L_{III}$ subshell X-ray production cross-section $\sigma^x_{L_{III}}$, total photoionization cross-section of $L_{III}$ and higher subshells $\sigma_{a_{III}}$ along with theoretical values of $L_{III}$ subshell fluorescence yield $\omega_3$ (Krause, 1979) has been then used in expression (4.3) to obtain the value of $L_{III}$ subshell absorption edge jump factor ($J_{L_{III}}$).

4.4 Measurement of $L_{III}$ subshell absorption edge jump ratio ($r_{L_{III}}$)

The presently measured values of $L_{III}$-subshell absorption edge jump factor ($J_{L_{III}}$) has been further used to deduced the values of corresponding jump ratios ($r_{L_{III}}$) in
elements under study by using the relation

\[ r_{ir} = \frac{1}{1 - J_{ir}} \]  

(4.11)

### 4.5 Result and discussion

The \( L_i \), \( L_a \) and \( L_\beta \) X-ray production cross-section of W, Au, Hg and Pb elements at incident gamma ray energy of 59.54 keV has been measured experimentally employing expression (4.5), using the procedure describe in section 4.2.2. Table 4.2 shows the experimental and theoretical values of \( L_i \), \( L_a \) and \( L_\beta \) X-ray production cross-section. Theoretical values of aforesaid elements has been calculated using following relations

\[ \sigma_{Li}^x = [\sigma_1 f_{12}f_{23} + f_{13}] + \sigma_2 f_{23} + \sigma_3 \omega_3 F_{3\ell} \]  

(4.12)

\[ \sigma_{La}^x = [\sigma_1 f_{12}f_{23} + f_{13}] + \sigma_2 f_{23} + \sigma_3 \omega_3 F_{3\alpha} \]  

(4.13)

\[ \sigma_{L\beta}^x = \sigma_1 \omega_1 F_{1\beta} + [\sigma_1 f_{12} + \sigma_2] \omega_2 F_{2\beta} + [\sigma_1 f_{12}f_{23} + f_{13}] + \sigma_2 f_{23} + \sigma_3 \omega_3 F_{3\beta} \]  

(4.14)

Where \( \sigma_1, \sigma_2 \) and \( \sigma_3 \) and \( \omega_1, \omega_2 \) and \( \omega_3 \) are \( L_i \), \( L_\alpha \) and \( L_\beta \) subshell photoionization cross-sections and subshell fluorescence yields respectively. \( F_{3\ell} \) is the fraction of intensity of X-rays originating from \( L_\beta \) transitions which contribute to the \( L_i \) peak of L X-ray spectrum. All other F’s are similarly defined. \( f_{12} \) is the Coster-Kronig transition probability of shifting of electron from \( L_i \) subshell to \( L_\alpha \) subshell. All other f’s are similarly defined. In above expression, values of L subshell photoionization cross-sections have been taken from the tables of Scofield (1973). Whereas, \( L_\beta \) subshell fluorescence and Coster-Kronig transitions \( f_{ij} \)’s has been taken from the compilation of Krause (1979) and values for decay rates \( F_{ij} \)’s for different L X-ray lines have been
taken from the compilation of Scofield et al. (1974). A comparison of the present experimentally measured values of L\textsubscript{I} X-ray production cross-section with theoretical values shows that values are in good agreement within experimental uncertainty.

From the measured values of $\sigma^x_{L\textsubscript{I}}$, $\sigma^x_{L\textsubscript{II}}$ and $\sigma^x_{L\textsubscript{III}}$, the contribution of L\textsubscript{I} and L\textsubscript{II} subshell cross-sections have been subtracted to obtain the values of $\sigma^x_{L\textsubscript{III}}$, $\sigma^x_{L\textsubscript{III}}$, and $\sigma^x_{L\textsubscript{III}}$ X-ray production cross-sections of L\textsubscript{III} subshell only. Finally the values of $\sigma^x_{L\textsubscript{III}}$ has been obtained using following relation

$$\sigma^x_{L\textsubscript{III}} = \sigma^x_{L\textsubscript{III}} + \sigma^x_{L\textsubscript{III}} + \sigma^x_{L\textsubscript{III}}$$  \hspace{1cm} (4.15)

In second phase of experiment, total interaction cross-section ($\sigma_I$) of aforesaid target elements has been measured using expression 4.10 employing transmission geometry in a different experimental setup as shown in figure 3.8. Results have been shown both in tabular form (Table 4.3) and in graphical form (figure 4.3). A good agreement has been achieved between experimental and theoretical values. Total photoionization cross-section $\sigma_{\text{LIII}}$ of L\textsubscript{III} and higher subshells has been obtained from the measured values of total atomic cross-section ($\sigma_I$) by subtracting the scattering contribution and photoionization contribution of K, L\textsubscript{I} and L\textsubscript{II} shell/subshell.

Finally, the measured values of L\textsubscript{III} subshell absorption edge jump factor ($J_{\text{LIII}}$) and absorption edge jump ratio ($r_{\text{LIII}}$) along with theoretical values calculated using XCOM (Berger and Hubbell, 1987) and FFAST (Chantler et al., 2005) for elements W, Au, Hg and Pb has been shown in Table 4.4 and 4.5 as well as in graphical form as shown in figure 4.4 and 4.5 respectively. It has been observed from these Tables and figures that the measured values of L\textsubscript{III} subshell absorption edge jump
factor \( J_{III} \) and absorption edge jump ratio \( r_{III} \) are in good agreement with calculated values within experimental uncertainties.

The overall estimated error associated with present measurement is of the order of ~6%, which include uncertainty involved in evaluation of different parameters such as such area under photo peak (i.e. statistical 1%), target thickness and self absorption correction factor (~2-3%) and critical geometrical factor <5 % etc. Present results clearly show that EDXRF technique used is an efficient and reliable for measuring L_{III} subshell absorption edge jump ratio and jump factor.
Table 4.2: Comparison of the measured values of $L_i$ ($i=l, \alpha$ and $\beta$) X-ray production cross-section with calculated values.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Element</th>
<th>L X-ray peak</th>
<th>Experimental values (b/atoms)</th>
<th>Theoretical values (b/atoms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>W-74</td>
<td>$L_l$</td>
<td>3.5</td>
<td>3.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$L_\alpha$</td>
<td>75</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$L_\beta$</td>
<td>112</td>
<td>118</td>
</tr>
<tr>
<td>2.</td>
<td>Au-79</td>
<td>$L_l$</td>
<td>7.5</td>
<td>7.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$L_\alpha$</td>
<td>151</td>
<td>157</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$L_\beta$</td>
<td>160</td>
<td>167</td>
</tr>
<tr>
<td>3.</td>
<td>Hg-80</td>
<td>$L_l$</td>
<td>8.5</td>
<td>8.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$L_\alpha$</td>
<td>168</td>
<td>165</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$L_\beta$</td>
<td>174</td>
<td>181</td>
</tr>
<tr>
<td>4.</td>
<td>Pb-82</td>
<td>$L_l$</td>
<td>10.7</td>
<td>10.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$L_\alpha$</td>
<td>205</td>
<td>202</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$L_\beta$</td>
<td>209</td>
<td>216</td>
</tr>
</tbody>
</table>
Table 4.3: Comparison of the measured values of total atomic cross-section ($\sigma_t$) with calculated values.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Element</th>
<th>Experimental values (b/atoms)</th>
<th>Theoretical values (b/atoms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>W-74</td>
<td>1162</td>
<td>1156</td>
</tr>
<tr>
<td>2.</td>
<td>Au-79</td>
<td>1499</td>
<td>1511</td>
</tr>
<tr>
<td>3.</td>
<td>Hg-80</td>
<td>1571</td>
<td>1590</td>
</tr>
<tr>
<td>4.</td>
<td>Pb-82</td>
<td>1739</td>
<td>1761</td>
</tr>
</tbody>
</table>

$^a$ Obtained using standard transmission geometry.

$^b$ XCOM (Berger and Hubbell, 1987) values
Table 4.4: Comparison of the measured values of L$_{III}$ subshell absorption edge jump factors ($J_{L_{III}}$) with calculated values.

<table>
<thead>
<tr>
<th>S.NO.</th>
<th>Element</th>
<th>Experimental</th>
<th>Theoretical</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>W-74</td>
<td>0.604</td>
<td>0.605$^a$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.622$^b$</td>
</tr>
<tr>
<td>2.</td>
<td>Au-79</td>
<td>0.600</td>
<td>0.594$^a$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.603$^b$</td>
</tr>
<tr>
<td>3.</td>
<td>Hg-80</td>
<td>0.594</td>
<td>0.591$^a$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.599$^b$</td>
</tr>
<tr>
<td>4.</td>
<td>Pb-82</td>
<td>0.584</td>
<td>0.586$^a$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.594$^b$</td>
</tr>
</tbody>
</table>

$^a$ XCOM (Berger and Hubbell, 1987) values
$^b$ FFAST Chantler et al. (2005) values
Table 4.5: Comparison of the measured values of L\textsubscript{III} subshell absorption edge jump ratios ($r_{\text{jump}}$) with calculated values.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Element</th>
<th>Absorption jump ratio ($r_{\text{jump}}$)</th>
<th>Experimental</th>
<th>Theoretical</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>W-74</td>
<td>2.525</td>
<td></td>
<td>2.532\textsuperscript{a} 2.647\textsuperscript{b}</td>
</tr>
<tr>
<td>2.</td>
<td>Au-79</td>
<td>2.500</td>
<td></td>
<td>2.467\textsuperscript{a} 2.520\textsuperscript{b}</td>
</tr>
<tr>
<td>3.</td>
<td>Hg-80</td>
<td>2.463</td>
<td></td>
<td>2.448\textsuperscript{a} 2.502\textsuperscript{b}</td>
</tr>
<tr>
<td>4.</td>
<td>Pb-82</td>
<td>2.404</td>
<td></td>
<td>2.418\textsuperscript{a} 2.465\textsuperscript{b}</td>
</tr>
</tbody>
</table>

\textsuperscript{a} XCOM (Berger and Hubbell, 1987) values  
\textsuperscript{b} FFAST Chantler et al.(2005) values
Fig. 4.3: Variation of total atomic cross-section ($\sigma_t$) as a function of atomic number ($Z$).
Fig. 4.4: Variation of L_{III} subshell jump factor (J_{L_{III}}) as a function of atomic number (Z).
Fig. 4.5: Variation of L_{III} subshell jump ratio ($r_{LIII}$) as a function of atomic number (Z).