CHAPTER V

DISCUSSION OF THE RESULTS

AND

CONCLUSIONS
Discussion of the results:

In this chapter, we give the detailed discussions of the present experimental results. The procedure adopted to measure the intensity of fluorescence x-rays and the target criteria followed are described in chapter IV. The measured values of K-shell fluorescence yield ($\omega_K$) for various elemental and compound targets are presented in tables 4.11 to 4.21. Also we compare the present experimental values with the semiempirical values of Krause (Krause, 1979), with the theoretical values of Chen et al., (Chen et al., 1980), with the standard fitted values of Hubbell (Hubbell, 1989), and Hubbell et al., (Hubbell et al., 1994). We also compare the present experimental values with the experimental values obtained by others by employing different geometrical configurations.

Krause (Krause, 1979) generated the “adopted values” of $\omega_K$ for elements in the atomic number range $5 \leq Z \leq 110$. However he has not given the parametric fits. The data considered includes experimental fluorescence yields, theoretical radiative and non radiative rates, x-ray and Auger line widths and spectra and Coster-Kronig energies, Auger and Coster-Kronig yields. The uncertainties in the $\omega_K$ values with the Z range $50 \leq Z \leq 110$ is about 1%.

Chen et al., (Chen et al., 1980) have reported systematic relativistic (Dirac-Hartree-Slater) calculations of atomic K-shell Auger rates, including all possible transitions, for 25 elements with $18 \leq Z \leq 96$. These radiationless transition rates have been combined with relativistic x-ray emission probabilities to derive fluorescence yields.
The semiempirical formula introduced by Burhop (Burhop, 1955) has been accepted as the standard form and his expression

\[
\left( \frac{\omega_K}{1 - \omega_K} \right)^{1/4} = C_0 + C_1Z + C_2Z^2 + C_3Z^3 \quad (5.1)
\]

\[\sum C_iZ^i\]

can be rewritten in the form

\[
\omega_K = \left[ \sum C_iZ^i \right]^4 / \left\{ 1 + \left[ \sum C_iZ^i \right]^4 \right\} \quad (5.2)
\]

The most comprehensive and widely quoted fluorescence yield reference to date, is that of Bambynek et al. (Bambynek et al., 1972), who produced fitted fluorescence yield values from the "selected 'most reliable' experimental values" He, in 1984 reevaluated \(\omega_K\) values by incorporating about 100 new measurements subsequent to his 1972 (Bambynek et al., 1972) evaluation. Using a stepwise regression analysis with 119 selected \(\omega_K\) measurements, Bambynek fitted his new evaluation to the form in Eq. (5.2) above, with parameters \(C_i\):

\[
C_0 = 0.0370 \pm 0.0052
\]

\[
C_1 = 0.03112 \pm 0.00044
\]

\[
C_2 = (5.44 \pm 0.11) \times 10^{-5}
\]

\[
C_3 = -(1.250 \pm 0.070) \times 10^{-6} \quad (5.3)
\]

This fit generated \(\omega_K\) values in the atomic number range \(3 \leq Z \leq 110\).
In 1989, Hubbell (Hubbell, 1989) reviewed the x-ray fluorescence yield experimental and theoretical information and presented $\omega_K$ values using Bambynek's (Bambynek, 1984) parameters [Eqn. (5.3)] for all elements $1 \leq Z \leq 110$. In our thesis we refer to these values as 1989 fitted values of Hubbell. Tables and fits of the K-shell fluorescence yield $\omega_K$ are presented along with the comparison with Bambynek et al.'s (Bambynek et al., 1972) fit values and Krause's (Krause, 1979) 'adopted values'.

In the target range, $35 \leq Z \leq 110$, the 1984 fitted values clearly agrees with the 1972 values and the difference is only about 1%.

A new analysis was presented in 1994 by Hubbell et al. (Hubbell et al., 1994), using selected x-ray production cross sections and selected fluorescence yield measurements by both photons and charged particles from the period 1978 - 1993. They derived $\omega_K$ from XRP using the relation

$$\omega_K = \frac{\sigma_K^x}{\sigma_K}$$  \hspace{1cm} (5.4)

where $\sigma_K^x$ denotes the total measured x-ray production cross section and $\sigma_K$ is the K-shell ionization cross section, respectively. The values of the ionization cross sections were taken from Scofield tables (Scofield, 1973) for photons and from Cohen tables (Cohen, 1985) for protons. $\sigma_K^x$ measured x-ray production cross sections were evaluated by adding the ($K_\alpha$ and $K_\beta$) XRP cross sections for K x-rays.
In the cases where the XRP cross sections were reported at more than one incident energy of the exciting particle, the values of the $i^{th}$ shell fluorescence yields, $\omega_i$ ($i = K, L, M$), for an element were obtained by taking the weighted average of the $\omega_j$ values available at different incident energies, using the expression

$$\omega_i = W \sum [ \omega_j / (\Delta \omega_j)^2 ]$$  \hspace{1cm} (5.5)

$$W = 1 / \sum (\Delta \omega_j)^2$$  \hspace{1cm} (5.6)

where $\omega_j$ denotes the $j^{th}$ experimentally deduced fluorescence yield and $(\Delta \omega_j)$ represents the quoted uncertainty in the $j^{th}$ experimental value.

The averaged (for each $Z$) experimental values of fluorescence yields were least squares fitted to polynomials in $Z$ of the form

$$\omega_i = \sum a_n Z^n$$  \hspace{1cm} (5.7)

and the fitted values of K-shell fluorescence yields are presented in table 4 of this report. We refer to these values in our thesis as 1994 fitted values of Hubbell et al..

The values of K-shell fluorescence yields from the tables of Krause (Krause, 1979), Chen et. al. (Chen et. al., 1980), Hubbell (Hubbell, 1989), and Hubbell et. al. (Hubbell et. al., 1994) only for those elements used in the present experiment are listed in table 5.1.
Table 5.1
Comparison of K-shell fluorescence yield values obtained from theory, semiempirical fits and empirical fits.

<table>
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<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Thorium (90)</td>
<td>0.971</td>
<td>0.969</td>
<td>0.9691</td>
<td></td>
</tr>
<tr>
<td>Bismuth (83)</td>
<td>0.968</td>
<td>0.964</td>
<td>0.9643</td>
<td></td>
</tr>
<tr>
<td>Lead (82)</td>
<td>0.967</td>
<td>----- a</td>
<td>0.9634</td>
<td></td>
</tr>
<tr>
<td>Gold (79)</td>
<td>0.964</td>
<td>----- a</td>
<td>0.9604</td>
<td></td>
</tr>
<tr>
<td>Tungsten (74)</td>
<td>0.958</td>
<td>0.954</td>
<td>0.9538</td>
<td></td>
</tr>
<tr>
<td>Tantalum (73)</td>
<td>0.957</td>
<td>----- a</td>
<td>0.9522</td>
<td>0.983</td>
</tr>
<tr>
<td>Dysprosium (66)</td>
<td>0.941</td>
<td>----- a</td>
<td>0.9376</td>
<td>0.972</td>
</tr>
<tr>
<td>Terbium (65)</td>
<td>0.938</td>
<td>----- a</td>
<td>0.9349</td>
<td></td>
</tr>
<tr>
<td>Gadolinium (64)</td>
<td>0.935</td>
<td>----- a</td>
<td>0.9320</td>
<td></td>
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<tr>
<td>Europium (63)</td>
<td>0.932</td>
<td>0.929</td>
<td>0.9289</td>
<td>0.962</td>
</tr>
<tr>
<td>Samarium (62)</td>
<td>0.929</td>
<td>----- a</td>
<td>0.9255</td>
<td></td>
</tr>
<tr>
<td>Praséodymium (59)</td>
<td>0.917</td>
<td>----- a</td>
<td>0.9140</td>
<td>0.941</td>
</tr>
<tr>
<td>Lanthanum (57)</td>
<td>0.907</td>
<td>----- a</td>
<td>0.9049</td>
<td>0.928</td>
</tr>
<tr>
<td>Barium (56)</td>
<td>0.902</td>
<td>0.899</td>
<td>0.8997</td>
<td>0.920</td>
</tr>
</tbody>
</table>

--- a Value not given in table.
It is clear from Table 5.1 that the adopted values of Krause (Krause, 1979), theoretical values of Chen et. al. (Chen et. al., 1980), and fitted values generated from Bambynek's (Bambynek, 1984) parameters by Hubbell (Hubbell, 1989) are all in close agreement with each other. Whereas Hubbell et. al.'s (Hubbell et. al., 1994) values, which involves XRP cross sections are consistently more compared with any of those other values. We compare our results with all these values.

We have determined $\omega_K$ value for each target in several trials to ascertain the accuracy, reproducibility and the reliability of the method. As an example, we give, in table 4.11, $\omega_K$ values along with their associated errors obtained in six trials, and their weighted average at an incident photon energy of 123.6 keV for tantalum elemental target and for barium nitrate compound target. Of course the photon energy considered is the weighted average of gamma rays from Co-57 source. In table 4.11, we also compare our $\omega_K$ values with the 1989 fitted values of Hubbell and 1994 fitted values of Hubbell et. al. We see in table 4.11, in the case of tantalum elemental target, the measured values of $\omega_K$ in six trials are not only in close agreement amongst themselves but also in close agreement with the 1989 fitted values of Hubbell. However it is less compared to the 1994 fitted values of Hubbell et. al., and the percent deviation is -3%. This indicates that our measured values seem to favor the Bambynek’s parameter values for the generation of $\omega_K$ values rather than those involve XRP cross sections (Hubbell et. al., 1994 values).
The same is true in the case of barium nitrate (a compound target) also. The values measured in different trials agree amongst themselves indicating the reliability and reproducibility and accuracy of the method for compound targets. Also as in the case of elemental tantalum target, the $\omega_K$ values of barium favors agreement with the 1989 fitted values of Hubbell and which in turn is in agreement with the theoretical and semiempirical values. The weighted average value of $\omega_K$ differs slightly from the 1994 fitted value of Hubbell et. al., as the percent deviation is about -3%. Therefore it is interesting to point out here that our measured value of $\omega_K$ for the medium Z compound target also, the trend is same that is favoring the 1989 fitted value of Hubbell rather than 1994 fitted value of Hubbell et. al..

We must point out here that in the case of barium nitrate compound, the barium elements are surrounded by different low Z elements namely nitrogen and oxygen. We have selected the thickness of the target such that the attenuation of fluorescence x-rays in the target is very less, as discussed already in chapter IV under thickness criterion. Since the measured value of $\omega_K$ for barium nitrate is in close agreement with the standard fitted value, we can infer that the fluorescence x-rays of barium are not subjected to scattering effects in the foil by a significant amount because of the presence of low Z elements in the target. Obviously the fluorescence x-rays produced due to the interaction of incident photons with low Z elements present in the compound are not interfering in the region of interest as they are far away from it. These results (for tantalum elemental and barium nitrate compound targets), indicate that the present method can easily be employed to determine the K-shell fluorescence yields for elements either from the
elemental target form or from the form of compound target when the constituent elements except the interested element are all of low \( Z \) values.

To test the credibility of the present method we have selected some other elemental and compound targets to determine the K-shell fluorescence yield values.

In table 4.12, we present \( \omega_K \) values for elemental targets namely lead, gold, and tantalum at the weighted average excitation energy of 123.6 keV photons. These experimental values of \( \omega_K \) are the weighted average values, taken from six trials for each of the targets. We compare our experimental values of \( \omega_K \) photons for lead and gold elemental targets with the 1989 fitted values of Hubbell only, as the 1994 Hubbell et. al., table do not provide \( \omega_K \) values for these elements. From table 4.12, it is clear that our measured values are in close agreement with 1989 fitted values of Hubbell and in case of tantalum it differs by about -3% from the 1994 values of Hubbell.

In table 4.13, we present \( \omega_K \) values for compound targets at the weighted average energy of 123.6 keV photons. These experimental values of \( \omega_K \) are the weighted average values, taken from six trials for each of the compound targets. We compare our experimental values of \( \omega_K \) for various elements obtained from their compound targets with the 1989 fitted values of Hubbell; and only for barium, 1994 table provide \( \omega_K \) value and so is compared.
We see, in table 4.13, the measured $\omega_K$ values are in close agreement with 1989 fitted values of Hubbell. Only in the case of barium, for which 1994 table provides $\omega_K$ value, indicates that 1994 value is more by about 3%.

Table 4.14 corresponds to rare earth compounds, covering the $Z$ range $57 \leq Z \leq 66$. The comparison of measured values with those of 1989 fitted values and 1994 fitted values show the same trend as before. Our values are consistently less than 1994 fitted values, but agree with 1989 fitted values.

In order to test the range of validity of the present method at higher incident photon energies, we have selected the two sources Ce-141 and Cr-51 of energies 145.4 keV and 320 keV respectively. The results obtained using these sources are presented in tables from 4.15 to 4.21, in the same pattern as those given in the case of excitation energy of 123.6 keV.

Here it must be pointed out that we did not measure $\omega_K$ values for rare earth compounds when we employed Ce-141 source, because the characteristic x-rays emitted from this source are of energy 35.478 keV, which is close to the region of interest, that is, the energy region of fluorescence x-rays emitted from rare earth compounds, 36.818-47.017 keV, interferes in the region of interest. The NaI(Tl) detector employed in the present investigation is not capable of discriminating the energies of these photons.
In table 4.15, we give the $\omega_K$ values along with their associated errors obtained in six trials at an incident photon energy of 145.4 keV for lead elemental target and for a lead nitrate compound target and compare our $\omega_K$ values with the 1989 fitted values of Hubbell only as the 1994 Hubbell et. al., table do not provide $\omega_K$ values for these elements. We see in table 4.15, the measured values of $\omega_K$ in six trials are not only in agreement amongst themselves but also in agreement with the 1989 fitted values of Hubbell.

In table 4.16, we present $\omega_K$ values for elemental targets namely lead, gold, and tantalum at the excitation energy of 145.4 keV. These experimental values of $\omega_K$ are the weighted average values, taken from six trials for each of the targets. We compare our experimental values of $\omega_K$ for lead and gold elemental targets with the 1989 fitted values of Hubbell only as the 1994 Hubbell et. al., table do not provide $\omega_K$ values for these elements. In the case of tantalum the value is compared with both the 1989 and 1994 fitted values. From table 4.16, it is clear that our measured values are in close agreement with 1989 fitted values of Hubbell. In the case of tantalum, our value differs by about -4% from the 1994 values of Hubbell. This supports the earlier trends obtained at the excitation energy of 123.6 keV.

In table 4.17, we present $\omega_K$ values for various compound targets at the excitation energy of 145.4 keV. These experimental values of $\omega_K$ are the weighted average values, taken from six trials for each of the targets. We compare our experimental values of $\omega_K$ for various elements obtained from their compound targets with the 1989 fitted values of Hubbell only, as the 1994 Hubbell et. al., table do not provide $\omega_K$ values for these elements. We see, in table
4.17, the measured $\omega_K$ values are in close agreement with 1989 fitted values of Hubbell.

The measurements are repeated for another excitation energy of 320 keV photons. In table 4.18, we present $\omega_K$ values for gold elemental target and for sodium tungstate compound target measured in six trials along with the weighted average value and compared with the 1989 fitted value of Hubbell only as the value is not available in 1994 table of Hubbell et. al. We see, in table 4.18, that as in the earlier cases at lower excitation energies, the measured values not only agree amongst themselves but also agree with the 1989 fitted values of Hubbell.

In table 4.19, we give $\omega_K$ values for elemental targets, for lead, gold, and tantalum obtained at the excitation energy of 320 keV. The measured values are compared with the 1989 fitted values of Hubbell and for the tantalum target the measured value is compared with both the 1989 and 1994 fitted values. The measured values are in close agreement with the 1989 fitted values and in the case of tantalum the measured value is less than 1994 fitted value by only about 2%.

In table 4.20, we present the measured values of $\omega_K$ for compound targets at the same excitation energy (320 keV). These experimental values of $\omega_K$ are the weighted average values, taken from six trials for each of the targets. We compare our experimental values of $\omega_K$ for various elements obtained from their compound targets with the 1989 fitted values of Hubbell only as the 1994 Hubbell et. al., table do not provide $\omega_K$ values for these elements. We see, in table 4.20, the measured $\omega_K$ values are in close agreement with 1989 fitted values.
Table 4.21 corresponds to rare earth compounds, covering the Z range $62 \leq Z \leq 66$. The comparison of measured values with those of 1989 fitted values and 1994 fitted values show the same trend as before. In case of dysprosium our values are consistently less than 1994 fitted values.

Finally we compare our results with those results obtained by various experiments adopting different techniques, over the years. They have employed single and double reflection geometries and radioactive sources of several milliCuries strength. In table 4.22, we give, the present experimental values of $\omega_K$ obtained at 123.6 keV (shown with superscript $a$), 145.4 keV (shown with superscript $b$) and 320 keV (shown with superscript $c$) incident photon energies. Since the $\omega_K$ values are independent of excitation energies, an average of the values obtained at different excitation energies can be taken. So we take the average value of $\omega_K$ from our measured values at three excitation energies and is presented in the last row of column 3, for each target (shown with superscript $d$). In table 4.22, we compare our values with the experimental values available in literature, for various elements covering from barium to thorium. In the fourth column, we present $\omega_K$ values obtained by others, employing different methods; again the average value of these may be taken since $\omega_K$ is independent of incident photon energy, and the same is given in the last row for each of the target in the fourth column. The numbers given in the last column refer to the corresponding reference numbers.
The other experimental values are collected from various sources, mainly from Fink et. al., which includes the results from the literature from 1934 to 1966, (Fink et. al., 1966), Bambynek et. al., which includes the selected most reliable experimental values from 1960 to 1972, (Bambynek et. al. 1972), and Hubbell et. al., which includes the results from the period 1978 to 1993, (Hubbell et. al.,1994).

However for gold and terbium elements no experimental values of \( \omega_K \) are available in the literature; as far as we know. Hence our \( \omega_K \) values for these elements may be considered as the first time measurements.

Also, we find, from the literature, that there is only one experimental value reported for thorium by Balakrishna et. al., in 1994. They have measured the K fluorescence yields using HpGe, low energy photon detector, employing the reflection geometry set up. They have used the Am-241 and Hg-203 radioactive sources of strengths 20 mCi and 40 mCi respectively. We see from table 4.22 our value of \( \omega_K \) for thorium is in agreement, within the experimental uncertainties, with the experimental value of Balakrishna et. al., indicating that our method of obtaining the values of K-shell fluorescence yields using very weak radioactive sources and simple \( 2\pi \) geometry set up is comparable with those obtained using reflection geometry and sophisticated equipments.
We see in table 4.22, that in case of bismuth, our experimental values of $\omega_K$ obtained at different energies range from 0.953 to 0.966. There are only three experimental values reported in literature for bismuth (Kinsey 1933, Kinsey 1939, and Mladjenovic 1955) and these values range from 0.934 to 0.976. So our values are in the range of values obtained by different methods. The average value of the present experimental results is in agreement, within the experimental uncertainties, with the average value of other experimental (Kinsey 1933, Kinsey 1939, and Mladjenovic 1955) values, as can be seen from table 4.22.

The same is true in the case of lead. Our experimental values of $\omega_K$ range from 0.956 to 0.975. For lead there are three experimental values reported in literature (Balakrishna et al., 1994, Durak et al., 1998, and Hansen et al., 1971) and these values range from 0.961 to 0.9732. Of these, the recent reported value is of Durak et al.'s. They have measured the K-shell fluorescence yields using a Ge(Li) detector and Co-57 radioactive source of strength 100 mCi by employing the reflection geometry. They have considered 122 keV photons only as primary photons, as, according to them the production of fluorescence x-rays due to the 136 keV photons emitted from the source is insignificant because of its low intensity and low photoionization cross section. We have considered the weighted average of these two energies, which comes out as 123.6 keV, because the present detector is not capable of resolving 122 keV and 136 keV photons. The photoelectric cross section values at 122 keV and 136 keV are almost same. Therefore the present experimental value can be compared with that of Durak et al.'s value. We found that our value is in agreement, within the experimental uncertainties, of 2%, with the Durak et al.'s value. The average value of the present experimental results for lead is in agreement, within the experimental
uncertainties, with the average value of other experimental (Balakrishna et. al., 1994, Durak et. al., 1998, and Hansen et. al., 1971) values.

We present the experimental values of $\omega_K$ for tungsten obtained at three photon energies and they range from 0.947 to 0.961. The average of these values comes out to be 0.955, as can be seen from table 4.22. For tungsten there are two experimental values reported in literature (Balakrishna et. al., 1994, and Durak et. al., 1998) and these values range from 0.956 to 0.9683. The average value of the present experimental results for tungsten is in agreement, within the experimental uncertainties, of about 1%, with the average of other experimental (Balakrishna et. al., 1994, and Durak et. al., 1998) values.

In table 4.22, we give the present experimental values for tantalum and the values varies from 0.942 to 0.977, the average of these values is 0.958. For tantalum there are three experimental values reported in literature (Balakrishna et. al., 1994, Durak et. al., 1998, and Sidhu et. al., 1988) and the values range from 0.955 to 0.9641. Sidhu et. al., have measured the K-shell fluorescence yields from a knowledge of nuclear decay parameters using the sources in liquid form and their specific activities were very high. The average value of the present experimental results is in close agreement with the value of Sidhu et. al.. The average value of the present experimental results is also in agreement, within the experimental uncertainties, of about less than 1%, with the other experimental (Balakrishna et. al., 1994, Durak et. al., 1998, and Sidhu et. al., 1988) values.

In case of dysprosium, we present the experimental results obtained at 123.6 keV and 320 keV energies only and the values range from 0.941 to 0.954. For dysprosium there are four experimental values reported in literature
Balakrishna et. al., 1994, Durak et. al., 1997, Graham et. al., 1961, and Sidhu et. al., 1988) and these values range from 0.943 to 0.975. The average value of the present experimental results for dysprosium is in agreement, within the experimental uncertainties, of about 1%, with the other experimental (Balakrishna et. al., 1994, Durak et. al., 1997, Graham et. al., 1961, and Sidhu et. al., 1988) values.

Now we present the experimental values for gadolinium obtained at two incident photon energies and they range from 0.935 to 0.954. For gadolinium there are two experimental values reported in literature (Balakrishna et. al., 1994, and Durak et. al., 1997) and these values range from 0.922 to 0.9458. The recent report is of Durak et. al.'s. The average value of the present experimental results is in close agreement with the value of Durak et. al.'s. The average value of the present experimental results is also in agreement, within the experimental uncertainties, of about 1%, with the other experimental (Balakrishna et. al., 1994, and Durak et. al., 1997) values.

In case of europium, because of its high hygroscopic property and the non-availability of sufficient quantity of the compound for us, we could measure the $\omega_K$ value at only one energy. For europium there are five experimental values reported in literature (Durak et. al., 1998, Morrand et. al., 1961, Singh et al., 1985, Sidhu et. al., 1988, and Suter et. al., 1962) and these values range from 0.908 to 0.957. Singh et. al., have determined the K-shell fluorescence yield of Eu with the results of the K-capture probabilities in the decay of Gd-153. Our value of $\omega_K$ is in agreement within the experimental uncertainties, of about less than 1%, with the value of Singh et. al., indicating that the present experimental values can be compared with the values obtained by the results of the K-capture.
probabilities in the decay of Gd-153. The present experimental result for europium is in agreement, within the experimental uncertainties, of about 1 %, with the average value of other experimental ( Durak et. al., 1998, Morrand et. al., 1961, Singh et. al., 1985, Sidhu et. al., 1988, and Suter et. al., 1962 ) values also.

In case of samarium, we give, the values obtained at two photon energies and they range from 0.916 to 0.922. For samarium there are two experimental values reported in literature ( Balakrishna et. al., 1994, and Durak et. al., 1998 ) and the literature values range from 0.933 to 0.9421. The average value of the present experimental results for samarium is in agreement, within the experimental uncertainties, of about 2 %, with the average value of the other experimental ( Balakrishna et. al., 1994, and Durak et. al., 1998 ) values.

The $\omega_K$ values for praseodymium, lanthanum, and barium were measured at only one excitation energy, that is 123.6 keV because of their highly hygroscopic nature. For praseodymium, there are two experimental values reported in literature ( Balakrishna et. al., 1994, and Sidhu et. al., 1988 ) and these values range from 0.88 to 0.930. The present experimental result for praseodymium is in agreement, within the experimental uncertainties, of about 1 %, with the average value of the other experimental ( Balakrishna et. al., 1994, and Sidhu et. al., 1988 ) values.

For lanthanum there are two experimental values reported in literature ( Al-Nasr et. al., 1987, and Kettele et. al., 1956 ) and these values range from 0.88 to 0.913. The present experimental result for lanthanum is in agreement,
within the experimental uncertainties, of about 2 %, with the other experimental 
( Al-Nasr et. al., 1987, and Kettele et. al., 1956 ) values.

For barium there are two experimental values reported in literature ( Al-
Nasr et. al., 1987, and Durak et. al., 1997 ) and the literature values range from 
0.85 to 0.9242. The present experimental result for barium is in agreement, within 
the experimental uncertainties, that is about 1 %, with the other experimental 
( Al-Nasr et. al., 1987, and Durak et. al., 1997 ) values.

From table 4.22, it is clear that the present experimental values are in close 
agreement, within the experimental uncertainties, with the other experimental 
values obtained by employing the different geometrical configurations and using 
the very strong radioactive sources.

The above results clearly establish that a $2\pi$ geometrical configuration 
employing a weak radioactive source can be utilized to produce accurate values of 
K-shell fluorescence yields. These values can be compared in accuracy with any 
other currently used method. The present method is easy to adopt and avoids 
shielding problems, and at the same time produces accurate $\omega_K$ values.