

# K-Shell X-ray Intensity Ratios: Compilation of Experimental Data, Semi-Empirical Modeling, and MCDF Calculations for $13 \leq Z \leq 99$

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**Abstract:** In the present study, we undertook a comprehensive compilation and critical reassessment of more than 740 reported measurements spanning over five decades, concerning six K-shell X-ray intensity ratios:  $K\alpha_2/K\alpha_1$ ,  $K\beta'_1/K\alpha_1$ ,  $K\beta_2/K\alpha_1$ ,  $K\beta'_2/K\alpha_1$ ,  $K\beta'_2/K\beta'_1$ , and  $K\beta_3/K\beta_1$ , for elements with atomic numbers in the range  $Z = 13$  (Al) and  $Z = 99$  (Es). The collected data were systematically organized in tabular form, and for each element, weighted mean values were derived, thereby establishing a sturdier baseline for cross-comparison throughout the dataset. Based on these weighted values, semi-empirical trends were delineated by fitting polynomial functions as a function of the atomic number.

Complementing this survey of experimental results, we performed 93 additional calculations employing the multiconfiguration Dirac-Fock (MCDF) method, explicitly incorporating relativistic effects. Standard deviations were represented graphically, enabling the identification of global trends while simultaneously highlighting anomalous data points that may warrant re-measurement. Among the investigated ratios,  $K\alpha_2/K\alpha_1$  and  $K\beta_3/K\beta_1$  exhibited the most consistent behavior across the elemental sequence. Conversely,  $K\beta_2/K\alpha_1$  displayed significant dispersion at higher atomic numbers, most plausibly attributable to instrumental constraints such as spectral line overlap. The remaining ratios occupied an intermediate position, with discrepancies often traceable to a limited number of individual studies.

Overall, this work provides a renewed perspective on K-shell X-ray intensity ratios. By integrating an extensive review of prior measurements with semi-empirical adjustments and newly generated MCDF calculations, we establish a consolidated reference set intended to support future experimental applications and theoretical developments in atomic physics.

**Keywords:** X-rays, fundamental atomic parameters, intensity ratios, weighted average values, semi-empirical and MCDF calculation.

**Contents**

**1. Introduction.....**

**2. Survey of experimental works.....**

**3. Data analysis.....**

**4. Semi-empirical calculation.....**

**5. Theoretical calculation.....**

**6. Conclusion.....**

**7. Acknowledgements**

**References.....**

## 1. Introduction

It is not an easy task to imagine the state of science before 1895, the year Roentgen first noticed a faint trace of radiation that had never been described before. What we now call X-rays, invisible and intangible, entered laboratories almost by accident, yet they soon reshaped medicine, engineering practices, and experimental physics. In the years that followed, the instruments used to study them became sharper and more consistent. Spectroscopy gained greater clarity, while computer-based methods grew into practical tools. Intensity ratios, once poorly known and hard to pin down, began to serve as fixed reference points, allowing researchers to map the internal make-up of atomic matter. Features once hidden started to become visible. Their use spread widely, touching plasma studies, medical diagnostics, environmental testing, industrial surveys, and exploratory science. Two different naming systems are still in common use. The Siegbahn convention, which employs labels such as  $K\alpha_1$ , exists side by side with the IUPAC convention, which uses terms like  $K-L_3$  [1]. In this study, we adopt the Siegbahn notation, a system conceived expressly to portray radiative transitions with precision and clarity. Within this framework,  $K\alpha$  designates  $K-L$  transitions in IUPAC terms, while  $K\beta$  corresponds to  $K-M$  and  $K-N$  transitions, as summarized in Figure 1.

The study of X-ray intensity ratios has unfolded through several distinct phases since the middle of the twentieth century. In the earliest years, researchers focused mainly on calibration and what might be called measurement ‘stability’, because the reliability of any spectroscopic result rested on solid and reproducible reference points [2]. During the 1970s and 1980s, the field reached a new stage of maturity. Theoretical work gained depth and subtlety, as quantum mechanics in the form of sophisticated computer codes slowly found its place in the explanation of radiative phenomena. This shift offered a sharper and more intuitive view of what happens inside the atom when it emits X-rays. A major turning point came in 1974, when Scofield [3] introduced relativistic corrections into the calculation of radiative transition rates. His

contribution elevated the level of theoretical accuracy and altered the perception of precision in the generation of such numerical results. Around the same time, synchrotron sources and high-resolution detectors became available, allowing experiments to reach a steadiness and clarity that earlier tools could not deliver [4,5]. Analytical techniques such as least-squares fitting [6] were then introduced to interpret the growing body of measurements and to derive coherent numerical values. In 1975, Desclaux [7] developed the Multiconfiguration Dirac–Fock and General Matrix Element (MCDFGME) code, a computational scheme that enabled the calculation of atomic structures incorporating relativistic corrections by implementing the Multiconfiguration Dirac–Fock (MCDF) method. By the 1990s, Polasik [8] and collaborators applied this method to explore how valence electrons influenced  $K\beta/K\alpha$  ratios, especially in transition metals. At the same time, it became clear that the chemical environment could shape the emission spectra, adding extra complexity but also providing new interpretations [9-11]. Since then, the MCDF approach has been gradually refined. It can now account for more complex electron behavior and excited states with greater confidence. The modifications reported by Indelicato and Desclaux [12] represented an important step, improving the trustworthiness of results and the efficiency of the calculations. In the 2000s and 2010s, research slowly leaned toward the use of digital detectors and new ways of treating signals, which made X-ray intensity measurements both sharper and more delicate [13,14]. These steps cleared the path for shaping workable models built from broad gatherings of experimental data, which then made it possible to sketch semi-empirical ties between X-ray emission lines across many elements [15,16]. In the same years, calculation codes also grew, with new adjustments that allowed scientists to deal with bigger and more tangled atomic systems [17]. By the 2020s, progress in X-ray intensity ratio studies continued with the use of new experimental techniques and theoretical models [18-21]. Consequently, massive collections of data [22] enlarged the pool of X-ray spectral values. Thanks to this, the information became more precise and more

trustworthy for use in material science. In earlier work [23], we compiled more than 2100 experimental  $K\beta/K\alpha$  intensity ratio values and presented the weighted averages for each element. In the same study, new semi-empirical average ratios were calculated for elements from  $_{11}\text{Na}$  to  $_{96}\text{Cm}$ . Additional theoretical values were also obtained for specific elements using the MCDF method. In summary, the evolution of X-ray intensity ratio studies reflects a steady accumulation of progress across experimental practice, theoretical formulation, semi-empirical refinement, and computational innovation, now closely interwoven with modern technology. Collectively, these advances provide a solid and coherent basis for interpreting and forecasting reliable X-ray atomic parameters. Such knowledge plays a crucial role in materials science, where the precise characterization of matter continues to drive both scientific discovery and technological innovation. Building upon our previous systematic efforts focused on fundamental atomic parameter databases [24–35], this study advances that work by compiling X-ray intensity ratio data. The earlier databases, which encompassed essential atomic quantities, established a foundation for the precise characterization of atomic de-excitation processes. Continuing in this direction, the present work delivers a consistent dataset of intensity ratios designed to support both theoretical modeling and experimental validation.

In this work, we gathered over 740 values for 6 different K shell X-ray intensity ratios:  $K\alpha_2/K\alpha_1$ ,  $K\beta'_1/K\alpha_1$ ,  $K\beta_2/K\alpha_1$ ,  $K\beta'_2/K\alpha_1$ ,  $K\beta'_2/K\beta'_1$ , and  $K\beta_3/K\beta_1$ , published between 1969 and 2024, creating six new databases, followed by a comprehensive data analysis. To provide a concise summary of the elemental data, the calculation of weighted average values was performed for each element along with the associated dispersion parameter. The results were employed to calculate new semi-empirical values for the X-ray intensity ratios mentioned above. Also, new theoretical calculations using the MCDF method were performed for several elements. This work continues the tradition of consolidation and improvement to provide data

consumers with a convenient, curated source of data but importantly also shines light on the path towards future improvements.

## 2. Survey of experimental works

The reliability of K-shell X-ray intensity ratio measurements is fundamentally governed by three principal factors: the excitation source, the target material, and the detector system. The excitation source establishes the available energy for the ejection of inner-shell electrons and thereby delineates the range of atomic numbers accessible to investigation. Charged-particle beams afford considerable flexibility through the adjustment of experimental parameters, whereas photon sources derived from radioisotopes offer operational simplicity but inherently limited tunability. The target and its preparation exert a decisive influence, as phenomena such as self-absorption, surface contamination, and intra-material interactions can introduce systematic deviations if not rigorously controlled. Equally critical is the detector, whose resolving power determines the capacity to discriminate between closely spaced spectral lines—a capability of particular importance under conditions of spectral crowding.

Table 1 brings together  $K\alpha_2/K\alpha_1$ ,  $K\beta'_1/K\alpha_1$ ,  $K\beta_2/K\alpha_1$ ,  $K\beta'_2/K\alpha_1$ ,  $K\beta'_2/K\beta'_1$ , and  $K\beta_3/K\beta_1$  intensity ratios measured between 1969 and 2024. It lists the atomic data for elements from  $^{13}\text{Al}$  to  $^{99}\text{Es}$ , together with the matching references, excitation sources, target materials, and used detectors. The table covers more than fifty years of laboratory investigation carried out under a wide variety of conditions.

## 3. Data analysis

All intensity ratios used in this study come from earlier published papers and are displayed with their significant digits, and their assigned experimental errors. A broad list of these measurements is given in Tables 2 to 7, covering elements with  $13 \leq Z \leq 99$ , along with the first sources and the calculated weighted mean values. To simplify the presentation, the six ratios

under study ( $K\alpha_2/K\alpha_1$ ,  $K\beta'_1/K\alpha_1$ ,  $K\beta_2/K\alpha_1$ ,  $K\beta'_2/K\alpha_1$ ,  $K\beta'_2/K\beta'_1$ , and  $K\beta_3/K\beta_1$ ) will be collectively referred to as  $R$ . To obtain a representative value of the X-ray intensity ratios from multiple independent measurements, we employed the weighted mean formalism. Equation (1) defines the weighted average  $R_W$  of the experimental ratios  $\Delta R_{\text{EXP}-i}$ , where each measurement is weighted by the inverse square of its reported uncertainty  $\Delta R_{\text{EXP}-i}^2$ .

$$R_W \pm \varepsilon = \frac{1}{\sum_{i=1}^N \frac{1}{\Delta R_{\text{EXP}-i}^2}} \cdot \sum_{i=1}^N \frac{R_{\text{EXP}-i}}{\Delta R_{\text{EXP}-i}^2} \pm \frac{1}{\left(\sum_{i=1}^N \frac{1}{\Delta R_{\text{EXP}-i}^2}\right)^{\frac{1}{2}}} \quad (1)$$

In the weighted-average method, measurements with smaller statistical uncertainties contribute more significantly to the determination of the mean value, while those with larger uncertainties are correspondingly down-weighted. The uncertainty of the weighted mean,  $\varepsilon$ , is obtained according to the same weighting prescription and represents the effective precision of the combined dataset. Across the reviewed literature, the reporting of uncertainties was not uniform: in some cases, absolute values were provided alongside the measured ratios, whereas in others uncertainties were expressed as relative percentages [36–38]. For consistency, all reported uncertainties were converted to absolute values before performing the averaging procedure. For reports written as percentages, the uncertainty was worked out as:

$$\Delta R = (p/100) \times R \quad (2)$$

Here,  $p$  is the given percentage and  $R$  the paired experimental ratio. Two extra numbers,  $z_i$  and  $\bar{z}$ , appear in Tables 2 to 7. Their meaning will be explained in the next part.

Figure 2 shows how the experimental data points are spread as a function of the atomic number  $Z$  for the intensity ratios  $K\alpha_2/K\alpha_1$ ,  $K\beta'_1/K\alpha_1$ ,  $K\beta_2/K\alpha_1$ ,  $K\beta'_2/K\alpha_1$ ,  $K\beta'_2/K\beta'_1$ , and  $K\beta_3/K\beta_1$ . The large set of gathered results, together with the variety of methods and instruments, leads to clear scattering for some elements. Main notes taken from these spreads are summarized below:

Most of the experimental points sit between  $Z = 40$  and  $Z = 90$ . These are mostly heavy transition metals, together with the lanthanides and actinides. In these families, K-shell transitions shine strongly.

For lighter atoms ( $Z < 30$ ) and the very heavy ones ( $Z > 90$ ), records are thinner. The trail there is uneven. Out of all the ratios,  $K\alpha_2/K\alpha_1$  is seen the most. It is the easiest to notice and has turned into the anchor used in many works.

The other ratios  $K\alpha_2/K\alpha_1$ ,  $K\beta'_1/K\alpha_1$ ,  $K\beta_2/K\alpha_1$ ,  $K\beta'_2/K\alpha_1$ ,  $K\beta'_2/K\beta'_1$ , and  $K\beta_3/K\beta_1$  are seen less often. Their signals are weak, and the trials to detect them are tougher.

A thick cluster of points stands out for  $Z \approx 60-82$ . This stretch covers the lanthanides ( $57 \leq Z \leq 71$ ) and important elements like tungsten ( ${}_{74}\text{W}$ ) and platinum ( ${}_{78}\text{Pt}$ ). These are often picked as targets, which explains the heavy coverage. Sharp peaks also rise for  ${}_{67}\text{Ho}$ ,  ${}_{79}\text{Au}$ ,  ${}_{81}\text{Tl}$ , and  ${}_{82}\text{Pb}$ . These gain attention for practical applications, like imaging and fluorescence scans.

The distribution of available data is markedly asymmetric: certain regions of the periodic table are densely populated, whereas others remain sparsely represented. This imbalance complicates systematic tests of theoretical predictions across a broad range of elements. In particular, intensity ratios involving  $K\beta'$  lines are most frequently absent, owing to their intrinsically weak emission and the experimental difficulty of resolving them from adjacent spectral features, which significantly impedes accurate determination.

#### **4. Semi-empirical calculation**

The semi-empirical calculation of K shell X-Ray intensity ratios is especially noteworthy, since it helps bypass the limits of experimental data, which are often scattered, as well as theoretical models, which rest on heavy simplifications. This approach provides a steady and continuous representation of the evolution of how these ratios change with the atomic number  $Z$ . To

determine these semi-empirical values, we adopted a method based on a double polynomial modeling [15,16,39-40]. First, the transformed quantity,  $[R_W/(1 - R_W)]^{\frac{1}{4}}$ , where  $R_W$  denotes the weighted average value of experimental ratios, was plotted as a function of the atomic number  $Z$  (Fig. 15) and fitted by a third-degree polynomial  $g(Z)$ :

$$[R_W/(1 - R_W)]^{\frac{1}{4}} = \sum_{i=0}^3 a_i Z^i = g(Z), \quad (3)$$

In a second step, a corrective factor  $S$

$$S = \frac{R_{\text{EXP}}}{R_W} = \sum_{i=0}^3 b_i Z^i = f(Z), \quad (4)$$

fitted by a third-degree polynomial  $f(Z)$ , was introduced, as shown in Fig. 16.

The combination of these two fittings then leads to the final semi-empirical expression:

$$R_{\text{Semi-emp}} = f(Z) \times \frac{g(Z)^4}{1+g(Z)^4} \quad (5)$$

Table 8 contains a list of the fitting parameters for both equations (3) and (4), whereas a summary of the semi-empirical calculations of intensity ratios for elements with  $13 \leq Z \leq 99$  according to their target atomic numbers is presented in Tables 9-14.

Figures 3-8 show how the experimental-to-weighted average ratios are spread for the six K-shell X-ray intensity ratios:  $K\alpha_2/K\alpha_1$ ,  $K\beta'_1/K\alpha_1$ ,  $K\beta_2/K\alpha_1$ ,  $K\beta'_2/K\alpha_1$ ,  $K\beta'_2/K\beta'_1$ , and  $K\beta_3/K\beta_1$ , as a function of the atomic number  $Z$ . Each point marks a value reported in the literature between 1969 and 2024. The different marks identify the sources of the data. When all six ratios are viewed together, their patterns are not the same.  $K\alpha_2/K\alpha_1$  and  $K\beta_3/K\beta_1$  ratios (Fig. 3 and

Fig. 8) show the most stability, and that's been the case from the reference [36] to the most recent one [19]. In most cases, the relative deviations RD(%) stay under 5%. By contrast, the  $K\beta_2/K\alpha_1$  ratio (Fig. 5) shows far more scatter, especially in heavier elements. In some datasets, deviations climb above 15-20%. This is clearly seen in the data of McCrary et al. [41] and Campbell et al. [42], which fall well outside the expected range. The other ratios  $K\beta'_1/K\alpha_1$ ,  $K\beta'_2/K\alpha_1$ , and  $K\beta'_2/K\beta'_1$  (Fig. 4, Fig. 6, and Fig. 7) are more uniform overall, with most values straying by less than 10%. Still, a few exceptions exist. The results of Dasmahapatra and Mukherjee [43] and of Durak and Özdemir [44] show RD(%) above 12-15%. A striking case is given by Ximeng et al. [45] for the  $K\beta'_2/K\beta'_1$  ratio, where the deviation is close to 20%. In comparison, more recent studies, such as Anand et al. [46] and Sakar et al. [47], fall within  $\pm 5\%$  of the weighted mean. Overall, the picture is mixed. Most intensity ratios remain within 10% deviation and support the strength of the semi-empirical method. Yet some datasets, especially older ones, contain outliers reaching or going beyond 20%.

The graphical analysis (Fig 3-8) gives a good view of how consistent the experimental data are and helps spot possible outliers. Still, to judge how far each measurement differs from its weighted average, a more quantitative approach is needed. To this purpose, we introduce a standardized method, based on the  $z$ -score formalism, which measures the deviation of an individual ratio from the weighted mean relative to their combined uncertainties. The average  $z$ -score,  $\bar{z}$ , is determined for each element to quantify the overall coherence of the available measurements:

$$\bar{z} = \frac{\sum_{i=1}^n z_i}{n}, \quad (6)$$

where  $n$  stands for the number of experimental points for each element, and

$$z_i = \frac{R_{\text{EXP}-i} - R_W}{\sqrt{\Delta R_{\text{EXP}-i}^2 + \Delta R_W^2}}, \quad (7)$$

Here,  $R_{\text{EXP}-i}$  and  $R_{\text{W}}$  stand for the  $i$ -th experimental value and the elemental weighted mean of the  $R$  intensity ratio, respectively, and  $\Delta R_{\text{EXP}-i}$  and  $\Delta R_{\text{W}}$  indicate, respectively, the associated experimental and weighted uncertainties.

This method lets each data point be expressed in terms of both experimental and weighted uncertainties. It offers a clearer picture of how meaningful the observed deviations are and makes it easier to compare different datasets on the same statistical scale.

The standardized residuals  $z_i$  (Eq. 7) together with their average values  $\bar{z}$  (Eq. 6) (Figs 9-14) were plotted as a function of the atomic number  $Z$  for each of the six K-shell X-ray intensity ratios and displayed in Figs 3-8. The parameters  $z_i$  and  $\bar{z}$  show how reliable each data point is and reveal broader patterns across the studied atomic number range. When the values cluster close to zero, the data agree well. Large deviations, on the other hand, point to possible outliers (including for unidentified cause), underestimated errors, or effects that vary with the element.

The analysis of the standardized residuals provides a clearer picture of the consistency of the experimental data with respect to the weighted averages. For the  $K\alpha_2/K\alpha_1$  ratio (Fig. 9), most points fall within the interval  $-2 \leq z \leq +2$  with only a few isolated deviations exceeding this, as observed in Ito et al. [19] for  ${}_{14}\text{Si}$  and  ${}_{32}\text{Ge}$ , and Boehm [48] for  ${}_{69}\text{Tm}$ . A similar conclusion can be drawn for the  $K\beta_3/K\beta_1$  ratio (Fig. 14), which shows the narrowest distribution of residuals and stands out as the most reliable of the six ratios. The ratios  $K\beta'_1/K\alpha_1$ ,  $K\beta'_2/K\alpha_1$ , and  $K\beta'_2/K\beta'_1$  (Fig. 4, Fig. 6, and Fig. 7, respectively) display an acceptable level of consistency, although some noticeable deviations occur, particularly in the mid- to high- $Z$  region where values occasionally exceed  $|z| = 3$ , as for the values published by Ximeng et al. [45] for elements with  $Z = 64-68$ , as well the values published by De Pinho et al. [49] for  ${}_{90}\text{Th}$  and  ${}_{92}\text{U}$ . These discrepancies are attributable to specific experimental datasets but do not indicate a systematic bias, as the average  $\bar{z}$  values remain close to zero across the periodic table. In

contrast, the  $K\beta_2/K\alpha_1$  ratio (Fig. 11) shows the widest spread. This can be seen in several datasets [41,50-53], where many points fall well beyond the expected range, especially for heavy elements ( $Z > 70$ ). This pattern confirms that the ratio is highly sensitive to experimental issues such as line overlap and absorption effects. Finally, the  $z$ -score analysis shows that most intensity ratios are consistent and free from clear systematic bias. However, the  $K\beta_2/K\alpha_1$  data need special attention, as they require careful handling to secure trustworthy comparisons between semi-empirical and theoretical results.

## 5. Relativistic calculations

The Multiconfiguration Dirac–Fock (MCDF) formalism stands among the most reliable and insightful approaches for the theoretical treatment of radiative transitions. Firmly grounded in the Dirac equation, it naturally includes relativistic effects, whose influence becomes increasingly tangible as one moves toward elements of higher atomic number. Unlike other approaches based on a single electronic configuration, the MCDF method adopts a broader, multiconfigurational view, where several electronic arrangements coexist. This perspective unveils a more detailed picture of the atom and the processes underlying its radiation. In the specific case of K-shell X-ray intensity ratios, the method allows the evaluation of radiative transition probabilities between the K-, L-, and M-shell levels, accounting for both spin-orbit coupling and electron-correlation effects. Through this procedure, 93 new theoretical values were provided for the six intensity ratios chosen in this work, encompassing 21 elements in total. The ratios are computed according to Equations (8) through (13):

$$\left(\frac{K\alpha_2}{K\alpha_1}\right) = \frac{\sum_i (2J_i + 1) \sum_{j_2} W_{ij_2}^R(KL_2)}{\sum_i (2J_i + 1) \sum_{j_1} W_{ij_1}^R(KL_3)}, \quad (8)$$

$$\left(\frac{K\beta'_1}{K\alpha_1}\right) = \frac{\sum_i (2J_i + 1) [\sum_{j_2} W_{ij_2}^R(KM_3) + \sum_{j_3} W_{ij_3}^R(KM_2) + \sum_{j_4} W_{ij_4}^R(KM_{45})]}{\sum_i (2J_i + 1) \sum_{j_1} W_{ij_1}^R(KL_3)}, \quad (9)$$

$$\left(\frac{K\beta_2}{K\alpha_1}\right) = \frac{\sum_i(2J_i + 1)[\sum_{j_2} W_{ij_2}^R(KN_{23}) + \sum_{j_3} W_{ij_3}^R(KN_{23})]}{\sum_i(2J_i + 1) \sum_{j_1} W_{ij_1}^R(KL_3)}, \quad (10)$$

$$\left(\frac{K\beta'_2}{K\alpha_1}\right) = \frac{\sum_i(2J_i + 1)[\sum_{j_2} W_{ij_2}^R(KN_{23}) + \sum_{j_3} W_{ij_3}^R(KN_{45})]}{\sum_i(2J_i + 1) \sum_{j_1} W_{ij_1}^R(KL_3)}, \quad (11)$$

$$\left(\frac{K\beta'_2}{K\beta'_1}\right) = \frac{\sum_i(2J_i + 1)[\sum_{j_4} W_{ij_4}^R(KN_{23}) + \sum_{j_5} W_{ij_5}^R(KN_{45})]}{\sum_i(2J_i + 1)[\sum_{j_1} W_{ij_1}^R(KM_3) + \sum_{j_2} W_{ij_2}^R(KM_2) + \sum_{j_3} W_{ij_3}^R(KM_{45})]}, \quad (12)$$

$$\left(\frac{K\beta_3}{K\beta_1}\right) = \frac{\sum_i(2J_i + 1) \sum_{j_2} W_{ij_2}^R(KM_2)}{\sum_i(2J_i + 1) \sum_{j_1} W_{ij_1}^R(KM_3)}, \quad (13)$$

where is the  $W_{ij}^R(KX)$  is the partial radiative transition rate for the emission  $KX$  ( $X = L_2, L_3, M_2, M_3, M_{45}$ ). For the calculation of the level energies and the transition rates, the MCDFGME code of Desclaux and Indelicato [7,54,12] was used. This code treats the Dirac-Coulomb-Breit Hamiltonian in a self-consistent way, incorporating QED corrections directly and adding some higher-order effects through perturbation theory. The electronic wave functions were optimized using a single-configuration model with full relaxation. Transition probabilities have been calculated in the Babushkin gauge, following the approach described in detail by Sampaio et al. [55].

Results of the MCDF calculations are presented alongside the semiempirical fit results in Tables (9) through (14). Agreement with both the weighted experimental results and the empirical fit results is considered to be good across the entire scope of the database, suggesting that the physics-based predictive tool can be used reliably to supplement quality experimental data.

## 6. Conclusion

This work gathers over five decades of experimental data on six K-shell X-ray intensity ratios ( $K\alpha_2/K\alpha_1$ ,  $K\beta'_1/K\alpha_1$ ,  $K\beta_2/K\alpha_1$ ,  $K\beta'_2/K\alpha_1$ ,  $K\beta'_2/K\beta'_1$ , and  $K\beta_3/K\beta_1$ ), encompassing 740 measured values for elements ranging from  $Z = 13$  to 99. By consolidating the available

measurements into a unified dataset and deriving weighted-average ratios, a reliable reference framework is established for future experimental determinations. In addition to this synthesis, new semi-empirical estimates were computed to ensure continuity across the full range of elements, thereby enhancing both consistency and completeness—qualities essential for practical applications. Complementary theoretical values obtained using the Multiconfiguration Dirac–Fock (MCDF) method for selected elements provide deeper insight into the mechanisms governing atomic transitions. Collectively, these components resolve long-standing discrepancies in earlier datasets and furnish a more robust foundation for subsequent applied studies and theoretical investigations of characteristic X-ray emissions. The presence of data with significant scatter, as well as elements with sparse or absent measurements, highlights immediate challenges and motivates the need for improved experimental efforts. The MCDF results further indicate that a comprehensive survey of all elements considered in this work would be highly valuable if conducted within this formalism. One important application of such synthetic datasets lies in their potential to serve as a physics-informed basis set, enabling the construction of a refined and globally consistent representation of experimental data.

## **7. Acknowledgements**

We gratefully acknowledge the support of the DGRSDT, Ministry of Higher Education and Scientific Research, Algeria. This work was done with the support of Mohamed El Bachir El Ibrahimi University. This work was also supported by the Fundação para a Ciência e Tecnologia (FCT), Portugal through contracts UIDP/50007/2020 (LIP) and UID/FIS/04559/2020 (LIBPhys). S.C. warmly acknowledges the financial support of Lancaster University, and A.F. gratefully acknowledges the support of the Joint Research Centre of the European Commission.

## Figure captions:

**Fig. 1.** Equivalence of IUPAC and Siegbahn notations in radiative transitions.

**Fig. 2.** Distribution of experimental  $R$  intensity ratios plotted against atomic number  $Z$ .

**Fig. 3.** Comparison of  $(K\alpha_2/K\alpha_1)_{\text{EXP}} / (K\alpha_2/K\alpha_1)_{\text{W}}$  across database references as a function of atomic number  $Z$ . ●: [56]; ●: [48]; ●: [57]; ●: [58]; ○: [59]; ○: [36]; ○: [49]; ○: [41]; ⊖: [60]; ⊖: [61]; ⊖: [62]; ⊖: [63]; ▲: [64]; ▲: [65]; ▲: [66]; ▲: [67]; ▲: [68]; ▲: [69]; ▲: [70]; ▲: [71]; ▲: [72]; ▲: [73]; ▲: [74]; ▲: [50]; ■: [51]; ■: [43]; ■: [75]; ■: [37]; ■: [76]; □: [44]; □: [52]; □: [45]; □: [77]; □: [78]; □: [79]; □: [80]; ▼: [81]; ▼: [53]; ▼: [82]; ▼: [83]; ▼: [38]; ▼: [84]; ▼: [46]; ▼: [85]; ▼: [86]; ▼: [87]; ▼: [88]; ▼: [47]; ▼: [89]; □: [19].

**Fig. 4.** Comparison of  $(K\beta'_1/K\alpha_1)_{\text{EXP}} / (K\beta'_1/K\alpha_1)_{\text{W}}$  across database references as a function of atomic number  $Z$ . ●: [57]; ●: [58]; ●: [49]; ●: [62]; ○: [63]; ○: [65]; ○: [69]; ⊖: [72]; ⊖: [73]; ⊖: [74]; ⊖: [43]; ▲: [44]; ▲: [90]; ▲: [45]; ▲: [80]; ▲: [53]; ▲: [82]; ▲: [83]; ▲: [38]; ▲: [84]; ▲: [46]; ▲: [85]; ▲: [87]; ▲: [47].

**Fig. 5.** Comparison of  $(K\beta_2/K\alpha_1)_{\text{EXP}} / (K\beta_2/K\alpha_1)_{\text{W}}$  across database references as a function of atomic number  $Z$ . ●: [41]; ●: [42]; ●: [68]; ●: [70]; ●: [50]; ○: [51]; ○: [52]; ○: [53]; ○: [46].

**Fig. 6.** Comparison of  $(K\beta'_2/K\alpha_1)_{\text{EXP}} / (K\beta'_2/K\alpha_1)_{\text{W}}$  across database references as a function of atomic number  $Z$ . ●: [57]; ●: [58]; ●: [49]; ●: [62]; ○: [65]; ○: [72]; ○: [73]; ○: [43]; ⊖: [90]; ⊖: [91]; ⊖: [82]; ⊖: [38]; ▲: [87]; ▲: [47].

**Fig. 7.** Comparison of  $(K\beta'_2/K\beta'_1)_{\text{EXP}} / (K\beta'_2/K\beta'_1)_{\text{W}}$  across database references as a function of atomic number  $Z$ . ●: [59]; ●: [49]; ●: [93]; ●: [65]; ○: [71]; ○: [72]; ○: [73]; ○: [74]; ⊖: [43]; ⊖: [93]; ⊖: [52]; ⊖: [90]; ▲: [45]; ▲: [91].

**Fig. 8.** Comparison of  $(K\beta_3/K\beta_1)_{\text{EXP}} / (K\beta_3/K\beta_1)_{\text{W}}$  across database references as a function of atomic number  $Z$ . ●: [94]; ●: [49]; ●: [61]; ●: [95]; ○: [64]; ○: [66]; ○: [96]; ○: [89].

**Fig. 9.** Graphical distribution of equations (6) and (7) applied to the ratio  $K\alpha_2/K\alpha_1$  versus atomic number  $Z$ .

**Fig. 10.** Graphical distribution of equations (6) and (7) applied to the ratio  $K\beta'_1/K\alpha_1$  versus atomic number  $Z$ .

**Fig. 11.** Graphical distribution of equations (6) and (7) applied to the ratio  $K\beta_2/K\alpha_1$  versus atomic number  $Z$ .

**Fig. 12.** Graphical distribution of equations (6) and (7) applied to the ratio  $K\beta'_2/K\alpha_1$  versus atomic number  $Z$ .

**Fig. 13.** Graphical distribution of equations (6) and (7) applied to the ratio  $K\beta'_2/K\beta'_1$  versus atomic number  $Z$ .

**Fig. 14.** Graphical distribution of equations (6) and (7) applied to the ratio  $K\beta_3/K\beta_1$  versus atomic number  $Z$ .

**Fig. 15.** Variation of  $[R_W/(1 - R_W)]^{\frac{1}{4}}$  across the atomic number range  $Z$  for the ratios  $K\alpha_2/K\alpha_1$ ,  $K\beta'_1/K\alpha_1$ ,  $K\beta_2/K\alpha_1$ ,  $K\beta'_2/K\alpha_1$ ,  $K\beta'_2/K\beta'_1$ , and  $K\beta_3/K\beta_1$ . Full line: fitted polynomial (3).

**Fig. 16.** Experimental-to-weighted ratio  $R_{EXP}/R_W$  vs  $Z$  by reference, for the ratios  $K\alpha_2/K\alpha_1$ ,  $K\beta'_1/K\alpha_1$ ,  $K\beta_2/K\alpha_1$ ,  $K\beta'_2/K\alpha_1$ ,  $K\beta'_2/K\beta'_1$ , and  $K\beta_3/K\beta_1$ . Full line: fitted polynomial (4).

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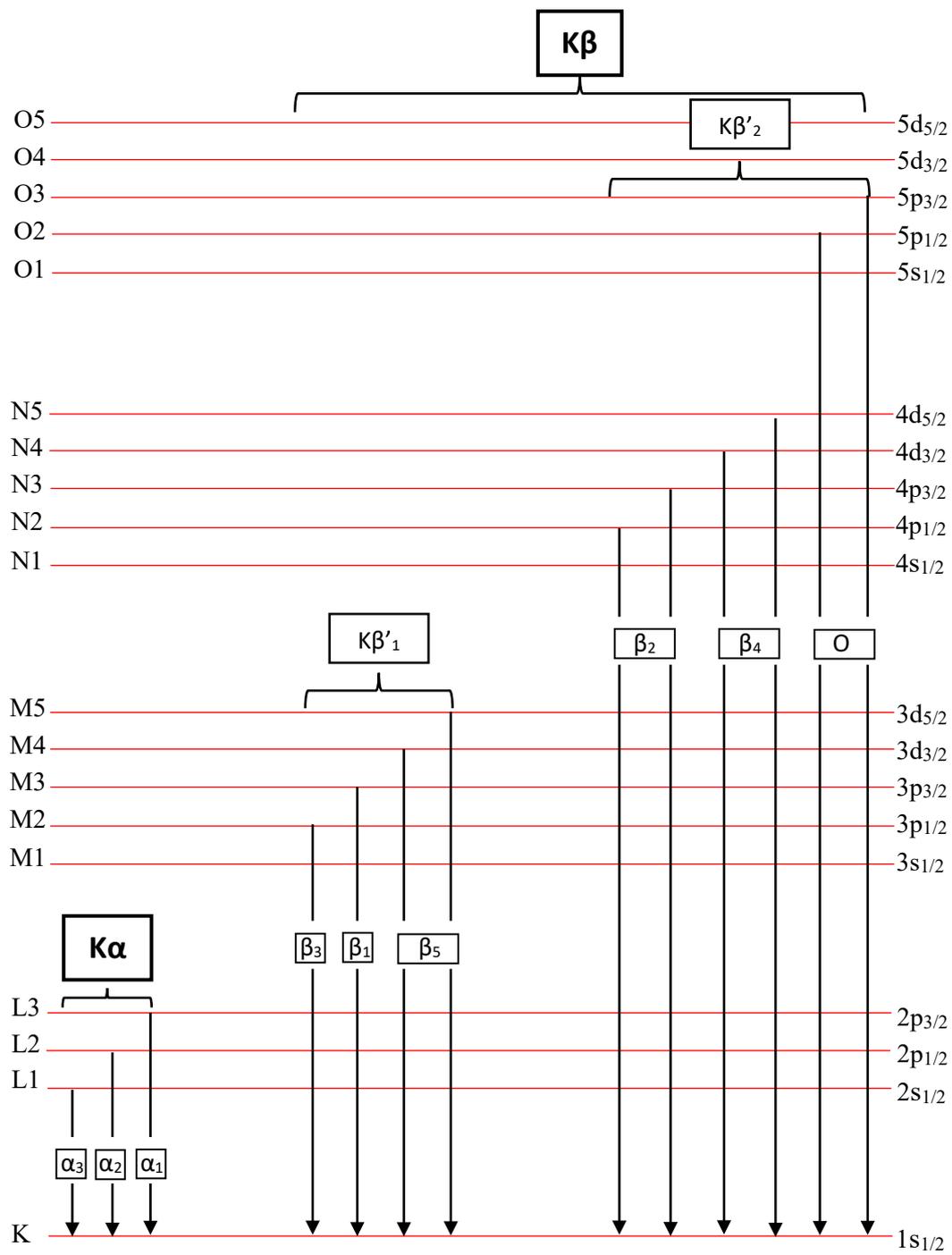


Figure 1:

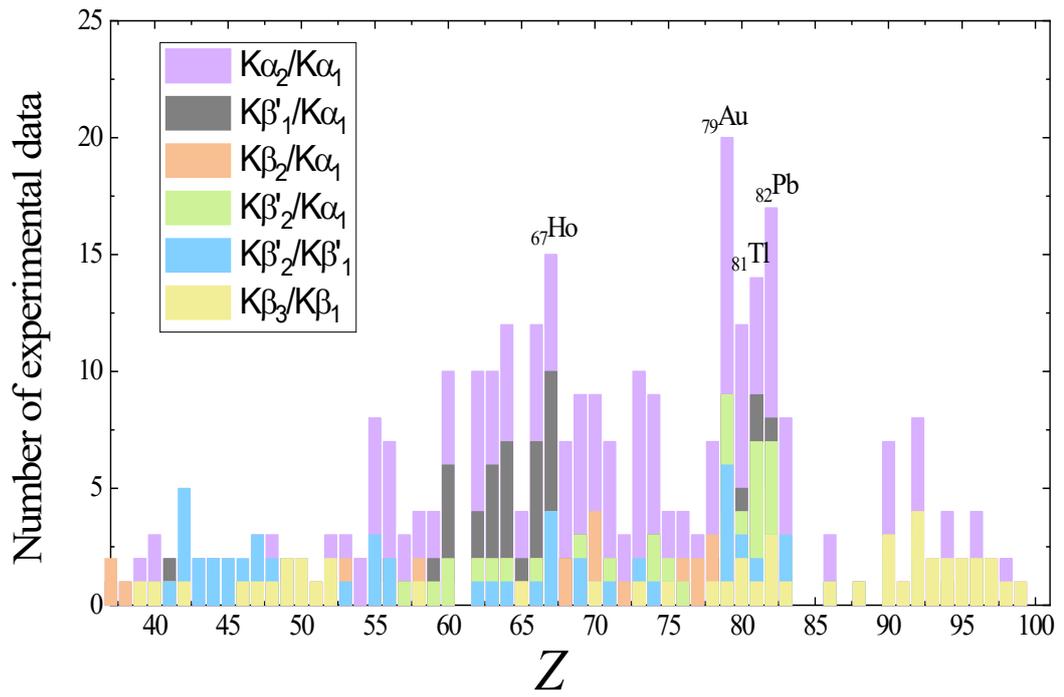
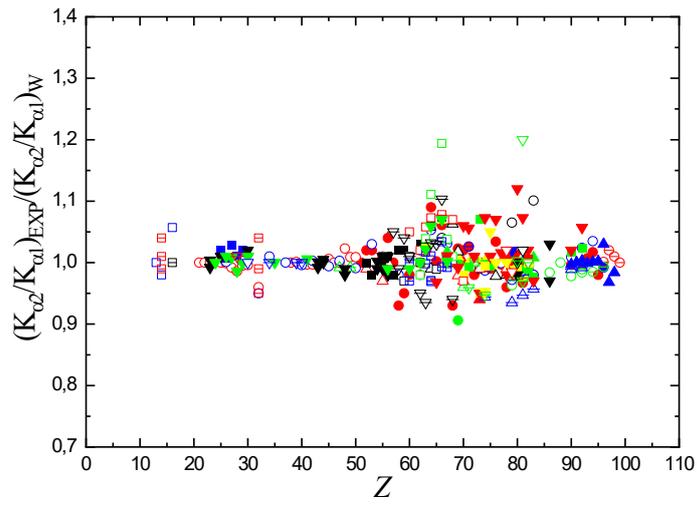


Figure 2:



**Figure 3:**

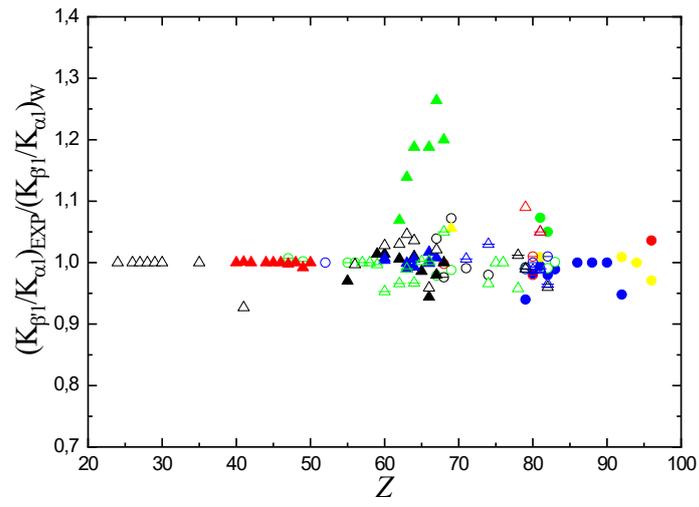


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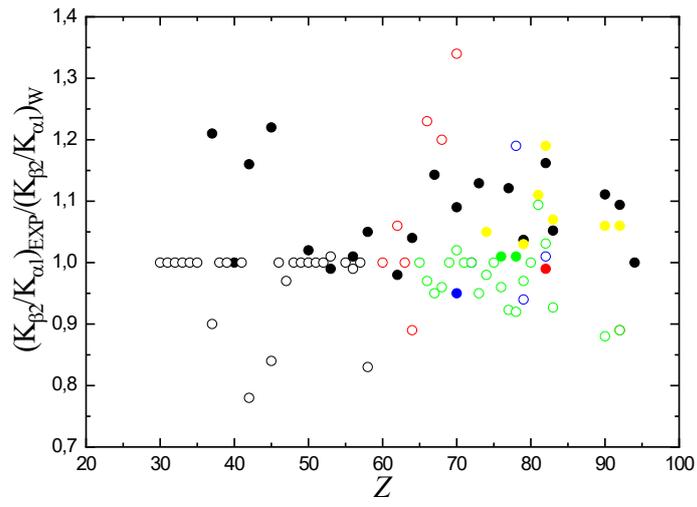


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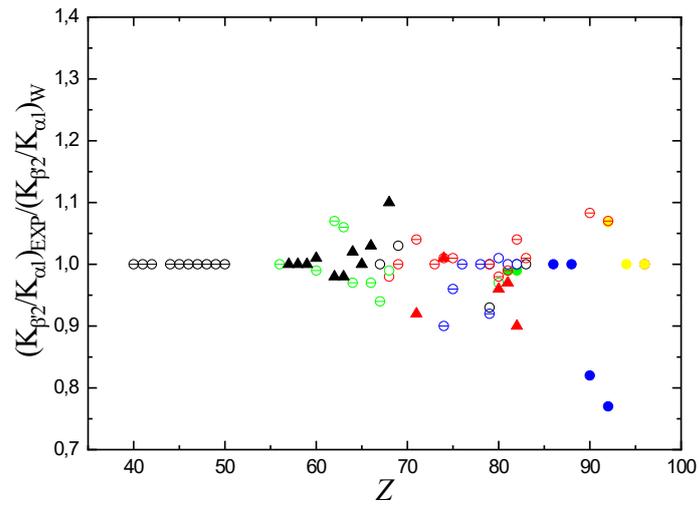


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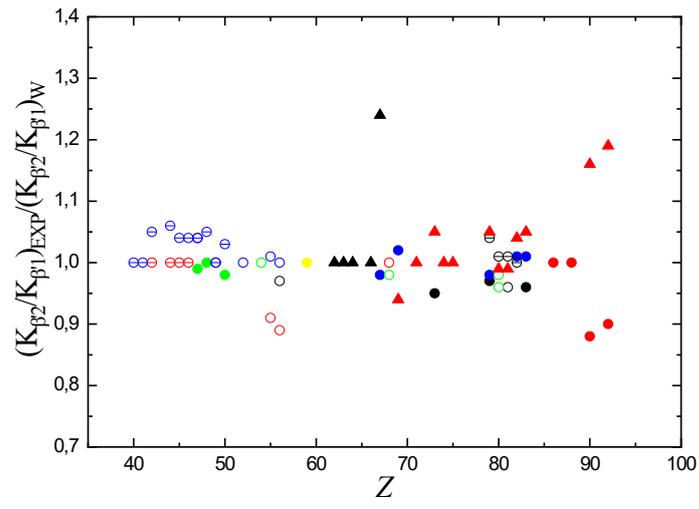


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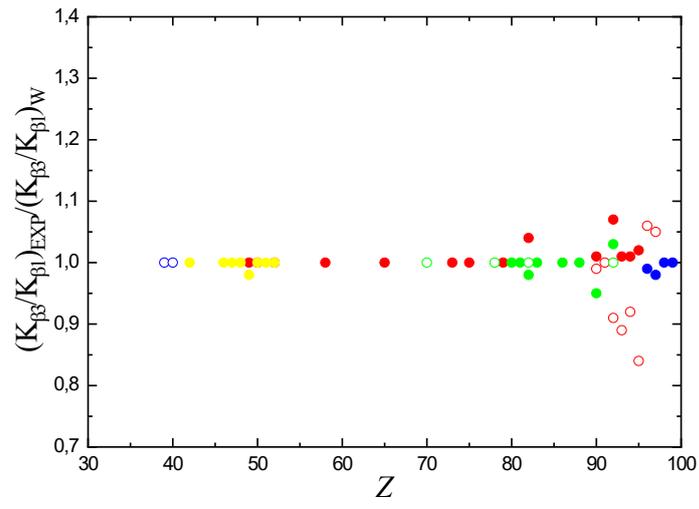
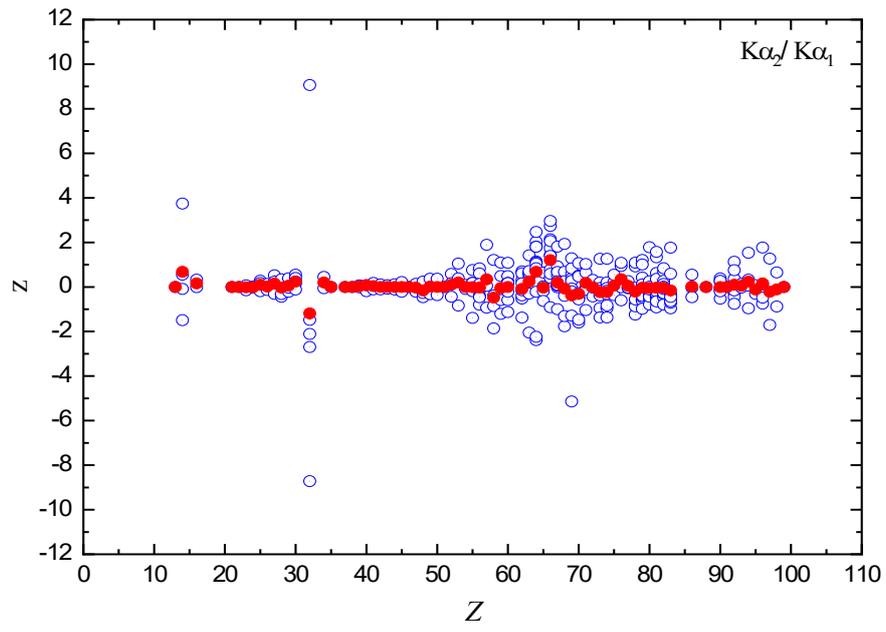


Figure 8:



**Figure 9:**

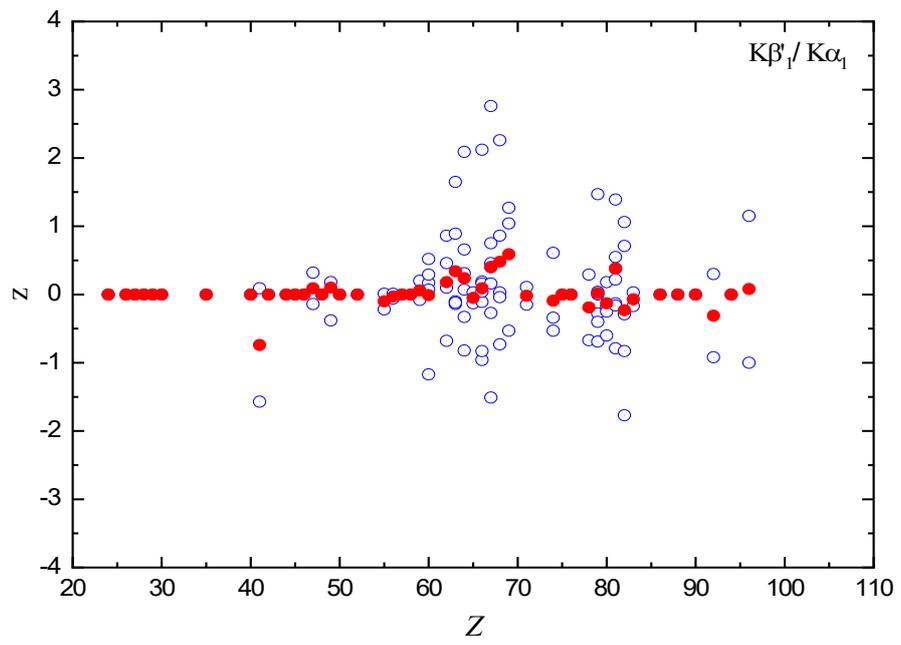


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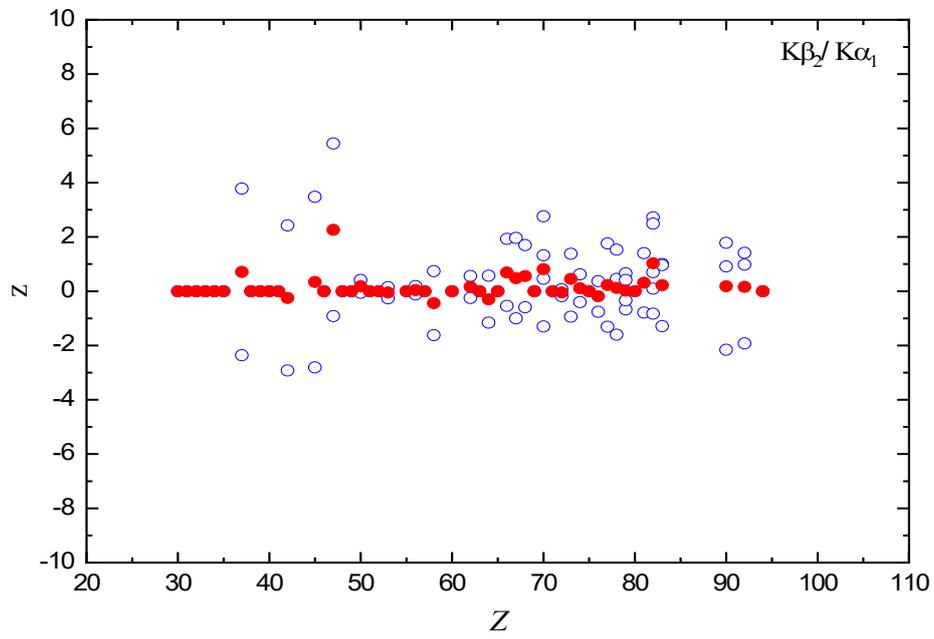


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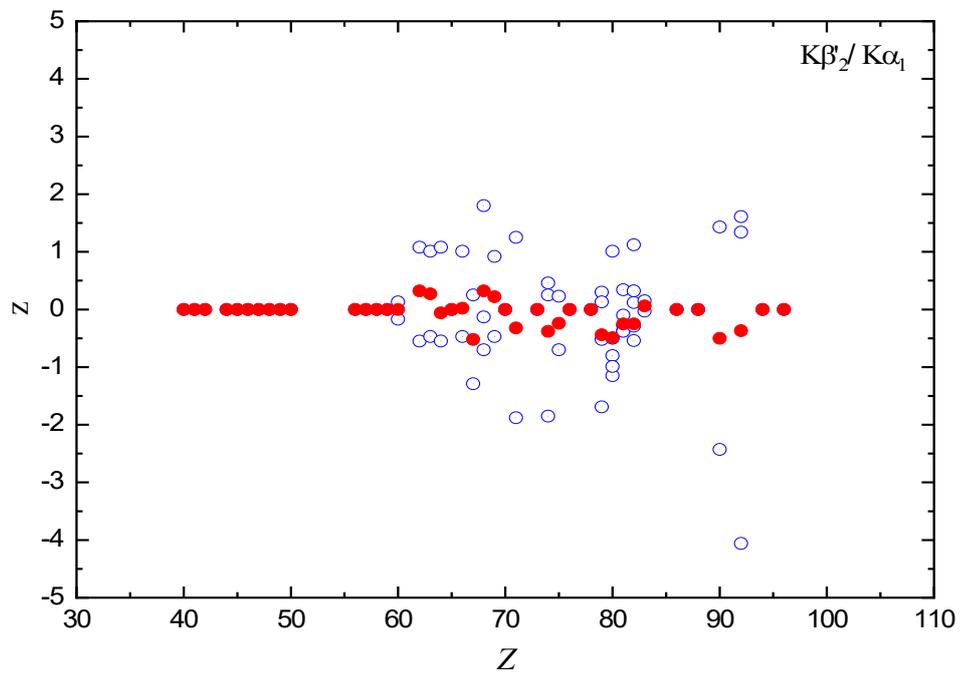


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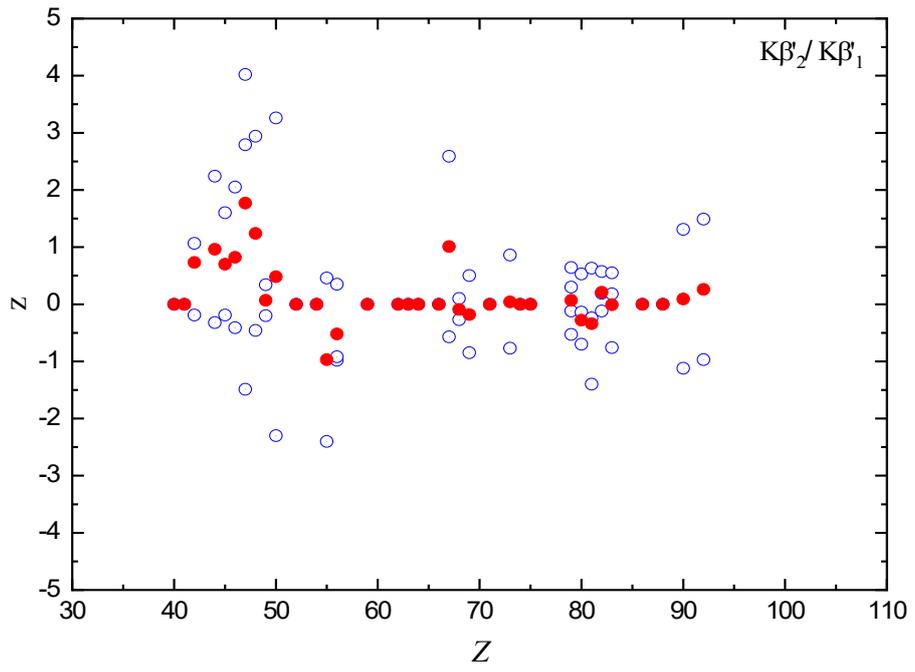


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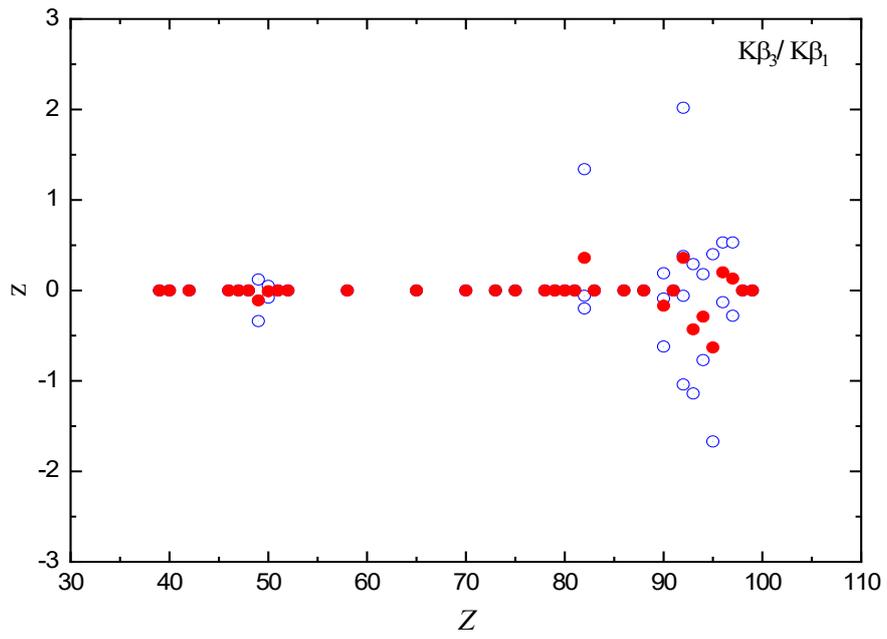


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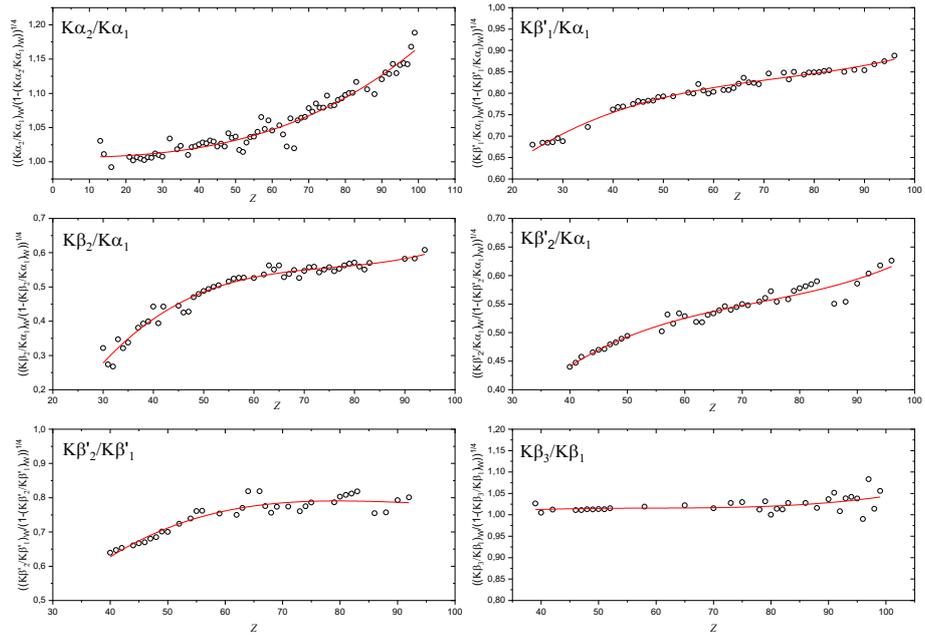
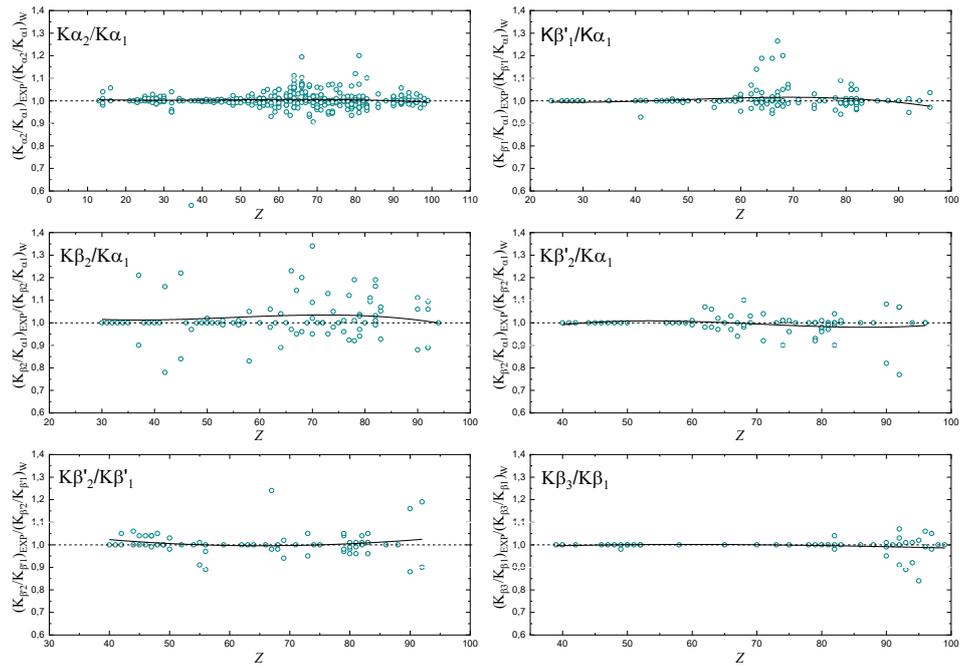


Figure 15:



**Figure 16:**

**Table 1.** Summary of atomic parameters ( $_{13}\text{Al}$ - $_{99}\text{Es}$ ), excitation sources, targets, detectors, and corresponding references.

| References | Atomic parameters  | Sources of Excitation   | Target samples   | Detectors  |
|------------|--|---|--|--|
| [56]       | $K\alpha_2/K\alpha_1$  | A radioactive $\text{Ta}^{182}$ source with an activity of 50 Ci  | 36 elements ranging from $_{51}\text{Sb}$ to $_{95}\text{Am}$ (metal foils)  | Cauchois-type curved crystal spectrometer and a Ge(Li) detector  |
| [48]       | $K\alpha_3/K\alpha_1$ & $K\alpha_2/K\alpha_1$  | A radioactive $^{169}\text{Yb}$ source with an activity of 01 Ci  | Tm   | Caltech 2m Curved Crystal Spectrometer   |
| [57]       | $K\alpha_2/K\alpha_1$ , $K\beta'_1/K\alpha_1$ , $K\beta'_2/K\alpha_1$ & $K\beta/K\alpha$               | A $^{249}\text{Cf}$ source weighing 4 $\mu\text{g}$   | $Z = 96$ (after alpha decay of $^{249}\text{Cf}$ )   | Ge(Li) detector with a resolution of 325 eV FWHM at 6.4 keV and 465 eV FWHM at 120 keV   |
| [58]       | $K\alpha_2/K\alpha_1$ , $K\beta'_1/K\alpha_1$ , $K\beta'_2/K\alpha_1$ & $K\beta/K\alpha$               | Thin layers of mylar on which a radioactive source has been installed   | $Z = 18-90$  | Si(Li) detector with a resolution of 260 eV FWHM at 6.4 keV for low- $Z$ elements ( $Z \leq 38$ ), and a Ge(Li) detector with a resolution of 460 eV FWHM at 6.4 keV for elements with <i>high Z</i> |
| [59]       | $K\alpha_2/K\alpha_1$ & $K\beta'_2/K\beta'_1$  | Electrons with incident energies between 150 and 900 MeV  | $Z = 29-83$<br>$^{29}\text{Cu}$ , $^{38}\text{Sr}$ , $^{42}\text{Mo}$ , $^{49}\text{In}$ , $^{69}\text{Tm}$ , $^{73}\text{Ta}$ , $^{79}\text{Au}$ , and $^{83}\text{Bi}$   | Si(Li) detector with a resolution of 430 eV FWHM at 14.4 keV   |
| [36]       | $K\alpha_2/K\alpha_1$  | Electrons with incident energies of 120 keV emitted by a $_{74}\text{W}$ filament   | 22 elements between $Z=21$ and $Z=50$ (metal foils)  | Bragg diffraction spectrometer   |
| [94]       | $K\beta_3/K\beta_1$  | Rays emitted by a $\gamma$ radioactive $^{182}\text{Ta}$ source with an activity of 50-Ci   | In, Sn, Te, Ce, Tb, Ta, Re, Au, Pb, Th, U, Np, Pu and Am (metal foils)   | Spectrometer with a bent quartz crystal in conjunction with a Ge(Li) detector  |
| [49]       | $K\alpha_2$ , $K\alpha_1$ , $K\beta_3$ , $K\beta_1$ , $K\beta_5$ , $K\beta_2$ , $K\beta_4$ & $K\beta'$ | Nuclear decay or external conversion of 662 keV photons generated from a $^{137}\text{Cs}$ source (K electron capture or internal conversion) | $Z = 17-82$<br>Au, Hg, Tl, Pb, Bi, Rn, Ra, Th and U  | Ge(Li) detector with a resolution of 700 eV FWHM at 122 keV  |
| [41]       | $K\alpha_1$ , $K\alpha_2$ , $K\beta_{1,3}$ & $K\beta_2$  | High-energy X-rays  | $Z = 20-94$<br>28 elements ranging from calcium to plutonium (pure and composite sheets $\text{CaF}_2$ , $\text{RbF}$ , $\text{NaI}$ , $\text{BaF}_2$ and $\text{CeO}_2$ ) | Ge(Li) detector with a resolution of 570 eV FWHM at 14 keV, Si(Li) detector with a resolution of 230 eV FWHM at 6 keV, and a Bragg diffraction spectrometer  |

|      |   |   |  |  |
|------|---|---|--|--|
| [60] | $K\alpha/K\beta$ &<br>$K\alpha_2/K\alpha_1$   | Electrons with incident energies ranging from 40 to 140 keV   | $Z = 27-79$<br>Cu, Zn, Ag, Sn, Dy and Au (made only from pure elements or their compounds)         | Ge(Li) detector with a resolution of 420 eV FWHM at 6.4 keV  |
| [61] | $K\alpha_2, K\beta_3$<br>& $K\beta_1$   | Decay of $\alpha$ $^{249}\text{Cf}$ and $^{254}\text{Es}$ , decay $\beta^-$ of $^{250}\text{Bk}$ , and electron capture decay of $^{251}\text{Fm}$  | Cm, Bk, Cf and Es  | Ge(Li) detector with a resolution of 500 eV FWHM at 122 keV  |
| [62] | $K\alpha_2/,K\alpha_1$<br>$K\beta'_1/K\alpha_1$<br>$K\beta'_2/K\alpha_1$<br>& $K\beta/K\alpha$  | Decay of $^{113}\text{Sn}$ , $^{203}\text{Hg}$ , $^{137}\text{Cs}$ , $^{243}\text{Am}$ and $^{249}\text{Cf}$ causing the emission of photons with energies of 24.1, 72.9, 31.0, 103.7 and 109.1 keV, respectively | $Z = 81, 92, 94$ and 96  | High-purity Ge detector with a resolution of 475 eV FWHM at 122 keV, as well as two Ge(Li) detectors with a resolution of 436 eV FWHM at 14.4 keV and 343 eV FWHM at 6.4 keV, respectively |
| [63] | $K\alpha_2/K\alpha_1,$<br>$K\beta/K\alpha$<br>& $K\beta'_1/K\alpha_1$   | Alpha particles with incident energies ranging from 40 to 110 MeV   | Ho, Tm, Lu, Ta, W, Pt, Au, Pb and Bi (natural and separate isotopes)                               | Intrinsic germanium detector with a resolution of 475 eV for X-rays with an energy of 100 keV  |
| [95] | $K\beta_3/K\beta_1,$<br>$K\beta_2/K\beta_1$<br>& $K\beta_{1,3}/K\beta_2$  | 45 keV electron bombardment X-ray tube  | Mo, Pd, Ag, Cd, In, Sn, Sb and Te (vacuum evaporation techniques were used to prepare the targets) | Curved crystal spectrometer with 2mm quartz crystal  |
| [64] | $K\alpha_2/K\alpha_1$ &<br>$K\alpha_3/K\alpha_1$  | Radioactive sources of $^{171}\text{Tm}$ , $^{181}\text{W}$ , $^{195}\text{Au}$ , and $^{207}\text{Bi}$ with activities of some microcuries   | Yb, Ta, Pt and Pb  | Ge(Li) Detector  |
| [65] | $K\beta/K\alpha,$<br>$K\alpha_2/K\alpha_1,$<br>$K\beta'_1/K\alpha_1$<br>& $K\beta'_2/K\alpha_1$   | Alpha particles with incident energies ranging from 9 to 155 MeV  | Sn, Ho, Tm, Au, Pb and Bi  | A high-purity Ge detector for X-ray detection, an intrinsic Ge detector for X-ray and low-energy $\gamma$ ray counting, and a Ge(Li) detector for ray counting $\gamma$                    |
| [66] | $K\alpha_2, K\alpha_1,$<br>$K\beta_3$ & $K\beta_1$  | Neutron capture   | $Z=90-98$<br>(Actinides)   | 5.76 m Dumond Type Curved Crystal Spectrometer   |
| [96] | $K\beta_3/K\beta_1,$<br>$K\beta_2/K\beta_1,$<br>$KO_{23}/K\beta_1,$<br>$KP_{2,3}/K\beta_1$<br>$K\beta_5/K\beta_1,$<br>$K\beta_4/K\beta_1,$<br>$KN_2 /,KN_3$ | Radioactive sources of $^{171}\text{Tm}$ , $^{195}\text{Au}$ , $^{207}\text{Bi}$ , and $^{235}\text{Np}$  | $Z = 70, 78, 82$ and 92  | Intrinsic planar Ge detector with a resolution of 435 eV FWHM at 84 keV  |

|      |   |   |   |   |
|------|---|---|---|---|
|      | & $KM_4$<br>/ $KM_5$  |   |   |   |
| [42] | $K\alpha_3/K\alpha_1$ ,<br>$K\beta_1/K\alpha_1$ &<br>$K\beta_2/K\alpha_2$   | Radioactive sources of<br>$^{207}\text{Bi}$ and $^{235}\text{Np}$   | $Z=82$ and $92$ (lead<br>and uranium)                                   | Intrinsic Ge crystal<br>mounted in a special<br>cryostat  |
| [67] | $K\beta/K\alpha$<br>$K\alpha_2/K\alpha_1$<br>& $K\alpha_3/K\alpha_1$  | 3.5 MeV protons   | $Z = 62-82$ (metal<br>sheets of Sm, Ho,<br>Tm, Lu, Ta, W, Au<br>and Pb) | Ge(Li) detector with a<br>resolution of 600 eV to<br>122 keV  |
| [68] | $K\alpha_1, K\alpha_2$ ,<br>$K\alpha_{1,2}, K\beta_{1,3}$ ,<br>$K\beta'_2, K\beta_1$ ,<br>$K\beta_2$ & $K\beta$                 | Decays of $^{192}\text{Ir}$ , $^{160}\text{Tb}$ ,<br>$^{169}\text{Yb}$ and $^{152}\text{Eu}$                        | $Z = 62, 64, 66, 69, 76$<br>and $78$                                    | Coaxial HPGe detector,<br>vertical plane HPGe<br>detector and Si(Li)<br>vertical detector   |
| [69] | $K\alpha_2/K\alpha_1$   | Radioactive ( $\beta^-$ or CE)<br>decay   | $Z=47-81$   | GeHP detector with a<br>resolution of 195 eV<br>FWHM at 6.4 keV   |
| [70] | $K\alpha_1, K\alpha_2$ ,<br>$K\beta'_1, K\beta'_2$ ,<br>$K\beta_{1,3}, K\beta_2$ ,<br>$K\alpha_{1,2}, K\beta_1$<br>& $K\beta_2$ | Decays of $^{210}\text{Pb}$ , $^{177}\text{Lu}$ ,<br>$^{170}\text{Tm}$ and $^{141}\text{Ce}$<br>radioactive sources | $Z = 59, 68, 70, 72$<br>and $84$  | Planar vertical HPGe<br>detector with FWHM<br>resolution of 459 eV at<br>122 keV and a vertical<br>Si(Li) detector with a<br>resolution of 165 eV at<br>5.9 keV |
| [71] | $K\alpha_1, K\alpha_2$ ,<br>$K\beta'_1, K\beta'_2$<br>& $K\alpha_{1,2}$   | Decay of $^{137}\text{Cs}$ and $^{203}\text{Hg}$<br>sources   | $Z = 56$ and $81$   | Planar vertical HPGe<br>detector with FWHM<br>resolution of 459 eV at<br>122 keV and a vertical<br>Si(Li) detector with a<br>resolution of 165 eV at<br>5.9 keV |
| [72] | $K\alpha, K\beta$<br>$K\alpha_2, K\alpha_1$ ,<br>$K\beta'_1$ & $K\beta'_2$  | Decays of $^{103}\text{Ru}$ , $^{131}\text{Ba}$ ,<br>$^{134}\text{Cs}$ and $^{166\text{m}}\text{Ho}$                | $Z = 45, 55, 56$ and $68$   | A coaxial HPGe<br>detector, a vertical<br>plane HPGe detector<br>and a Si(Li) detector  |
| [73] | $K\alpha, K\beta$<br>$K\alpha_2, K\alpha_1$ ,<br>$K\beta'_1$ & $K\beta'_2$  | Decays of $^{131}\text{I}$ , $^{166}\text{Ho}$ , $^{198}\text{Au}$<br>and $^{199}\text{Au}$                         | $Z = 54, 68$ and $80$ .   | Two coaxial HPGe<br>detectors, one planar<br>vertical HPGe detector<br>and two Si(Li)<br>detectors  |
| [74] | $K\alpha_2/K\alpha_1$ ,<br>$K\beta_1'/$<br>$K\alpha_1, K\beta_2'/$<br>$K\beta_1'$ &<br>$K\alpha/K\beta_1$                       | Radioactive decay (or EC)<br>$\beta$  | $Z = 47, 49, 52, 55$<br>and $56$  | HPGe detector with a<br>resolution of 195 eV<br>FWHM at 6.5 keV   |
| [50] | $K\alpha_2/K\alpha_1$ ,<br>$K\beta_1/K\alpha_1$ ,<br>& $K\beta_2$<br>/ $K\alpha_1$  | 121.9 keV photons from a<br>$^{57}\text{Co}$ source of 10 mCi<br>activity   | W, Au, TI, Pb, Bi<br>(thin films), Th and U<br>(disk pellets)           | Planar Ge detector with<br>a resolution of 170 eV<br>FWHM at 5.9 keV  |

|      |  |  |  |  |
|------|--|--|--|--|
| [51] | $K\alpha_1, K\alpha_2,$<br>$K\beta_{1,3}$ &<br>$K\beta_2$  | An X-ray tube operating at 60 kV, 2.5 mA with a +150 $\mu\text{m}$ Sn filter and a 50 $\mu\text{m}$ Mo filter; an X-ray tube operating at 40 kV, 3.0 mA with a 200 $\mu\text{m}$ Ag filter; and an X-ray tube operating at 8 kV, 0.6 mA without filter | Z = 14-92 (thin-film samples)  | EDXRF spectrometer equipped with a Si(Li) detector with a resolution of 145 eV for the Mn line $K\alpha$ |
| [92] | $K\beta/K\alpha$<br>& $K\beta'_2/K\beta'_1$  | 59.54 keV gamma rays produced from a $^{241}\text{Am}$ radioactive source with an activity of 200 mCi  | Mn, Ni, Cu, Ga, Ge, Ag, Cd, Sn and Sb (pure elements, alloys and compounds)                                      | Si(Li)   |
| [43] | $K\alpha_1, K\alpha_2,$<br>$K\beta'_1$ & $K\beta'_2$   | Decays of $^{197}\text{Hg}$ , $^{204}\text{Tl}$ , $^{203}\text{Hg}$ , and $^{207}\text{Bi}$  | Z = 79-82  | Two small volume HPGe detectors, as well as a small volume HPGe detector (LEPS)                          |
| [93] | $K\beta/K\alpha$<br>& $K\beta'_2/K\beta'_1$  | 59.54 keV gamma rays produced from a $^{241}\text{Am}$ point source of 200 mCi activity  | Fe, Co, Ni, Cu, Mo, Ru, Rh and Pd (Thick Sample of Grete Purity)   | Si(Li) detector with a resolution of 165 eV to 5.9 keV   |
| [75] | $K\beta/K\alpha,$<br>$K\alpha_2/K\alpha_1,$<br>& $K\beta_1/K\alpha_1$  | 122 keV photons produced from a $^{57}\text{Co}$ radioactive source  | Z = 69-92  | Ge(Li) detector with a resolution of 190 eV to 5.9 keV   |
| [37] | $K\alpha_2/K\alpha_1$<br>$K\beta_{1,3}/K\alpha_{1,2}$  | X-ray tube   | Cr, Mn, Fe, Co, Ni and Cu (3d transition metals)   | High-precision monocrystalline spectrometer in Bragg geometry  |
| [76] | $K\beta/K\alpha,$<br>$K\alpha_2/K\alpha_1,$<br>& $K\beta_1/K\alpha_1$  | 123.6 keV photons produced from a $^{57}\text{Co}$ radioactive source with 100 mCi activity  | Nd, Sm, Eu, Gd, Dy, Ho, Er, Yb, Ta, W, Hg, and Pb (Pure Circular Disc Samples)                                   | Collimated Ge(Li) detector with FWHM resolution of 190 eV at 5.9 keV                                     |
| [44] | $K\beta/K\alpha,$<br>$K\alpha_2/K\alpha_1,$<br>& $K\beta'_1/K\alpha_1$   | 59.54 keV gamma rays produced from a $^{241}\text{Am}$ point source of 100 mCi activity  | Z = 55-68 (pure rectangular samples)   | Si(Li) detector with a resolution of 188 eV FWHM at 5.9 keV  |
| [52] | $K\alpha_1/K\alpha,$<br>$K\alpha_2/K\alpha,$<br>$K\beta_1/K\alpha,$<br>$K\beta_2/K\alpha$<br>& $K\beta/K\alpha$          | Protons of 20, 22 and 25 MeV   | Nd, Sm, Eu, Gd, Dy, Er, and Yb (Nd, Sm, Eu, Gd, Dy, Er were as thin targets, as Yb was evaporated)               | Ge Low Energy Detector (LEGe) with a resolution of 180 eV FWHM at 5.96 keV                               |
| [90] | $K\beta'_1/K\alpha_1,$<br>$K\beta'_2/K\alpha_1$ &<br>$K\beta'_2/K\beta'_1$   | 3 MeV proton beam  | Z=40-59 (Pure Metal Targets)   | Si(Li) with a resolution of 140 eV at 5.9 keV  |
| [45] | $K\beta/,K\alpha$<br>$K\alpha_2/,K\alpha_1$<br>$K\beta'_1/,K\alpha_1$<br>$K\beta'_2/,K\beta_1'$<br>& $K\beta_3/K\beta_2$ | Protons of 3 MeV   | Z = 39, 51, 62, 63, 64, 66, 67 (targets were created from Y, Sb, Sm, Eu, Gd, Dy, Ho, Er nitrates on Mylar films) | Si(Li) detector with a resolution of 195 eV to 5.9 keV   |

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|------|---|--|--|---|
| [91] | $K\beta'_2/K\beta'_1$<br>& $K\beta'_2/K\alpha_1$  | Low-energy photons emitted by a $^{57}\text{Co}$ source of 100 mCi activity  | Tm, Yb, Lu, Ta, W, Re, Au, Hg, Tl, Pb, Bi, Th and U (Spectroscopically pure targets of $\text{Tm}_2\text{O}_3$ , $\text{Yb}_2\text{O}_3$ , $\text{Lu}_2\text{O}_3$ , Ta, $\text{Na}_2\text{WO}_4$ , Re, Au, $\text{Hg}_2(\text{NO}_3)_2 \cdot 2\text{H}_2\text{O}$ , $\text{Tl}_2\text{O}_3$ , Pb, $\text{Bi}(\text{CO}_3)_2$ , $\text{Th}(\text{NO}_3)_2 \cdot 2\text{H}_2\text{O}$ and $(\text{CH}_3\text{COOH})_2\text{UO}_2 \cdot 2\text{H}_2\text{O}$ in powder form) | Ge(Li) detector with a resolution of 190 eV to 5.96 keV                       |
| [77] | $K\alpha_1, K\alpha_2$<br>& $K\beta_{1,3}$  | X-ray tube consisting of a rhodium anode   | Al, Si and S (samples were placed in the elemental state and in various valence states: $\text{Al}_2\text{O}_3$ , $\text{SiO}_2$ , ZnS, $\text{Na}_2\text{S}_2\text{O}_5$ , $\text{Na}_2\text{SO}_4$ , $\text{FeS}_2$ , $(\text{NH}_4)_2\text{SO}_4$ , $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ and $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ )   | Ge and PET analyzer crystals are used in a wavelength dispersion spectrometer |
| [78] | $K\alpha_2/K\alpha_1$   | 2 MeV proton beam  | Sulfide and its compounds (S, FeS, $\text{TiS}_2$ , $\text{Na}_2\text{SO}_3$ , $\text{Fe}_2(\text{SO}_4)_3$ , $(\text{NH}_4)_2\text{SO}_4$ in powder form and then granulated)   | High-resolution crystal spectrometer in Johansson geometry                    |
| [80] | $K\alpha_2/K\alpha_1$<br>$K\beta'_1/K\alpha_1$<br>& $K\beta/K\alpha$                        | 59.5 keV gamma rays produced from a $^{241}\text{Am}$ radioactive source with 100 mCi activity   | Nd, Gd, Dy, Eu and Ho (pure sheets of Gd and Dy, and Nd, Eu and Ho in powder form)   | Si(Li) detector with a resolution of 180 eV at 5.9 keV                        |
| [79] | $K\alpha_2/K\alpha_1$<br>$K\beta_2/K\alpha_1$<br>$K\beta_1/K\alpha_1$<br>& $K\beta/K\alpha$ | 123.6 keV gamma rays produced from a $^{57}\text{Co}$ annular radioactive source with an activity of 25 mCi  | Hf (pure element and its compounds in powder form)   | Ultra-LEGe detector with a resolution of 150 eV to 5.9 keV                    |
| [81] | $K\alpha_2/K\alpha_1$<br>$K\beta_1/K\alpha_1$<br>& $K\beta/K\alpha$                         | Decay of $^{51}\text{Cr}$ , $^{55}\text{Fe}$ , $^{67}\text{Ga}$ , $^{99}\text{Tc}$ , $^{111}\text{In}$ , $^{131}\text{I}$ , $^{133}\text{Ba}$ , $^{133}\text{Xe}$ , $^{137}\text{Cs}$ , $^{201}\text{Tl}$ and $^{226}\text{Ra}$ , as well as a $^{241}\text{Am}$ annular radioactive source of 100 mCi activity and a $^{60}\text{Co}$ annular radioactive source of 100 mCi activity producing gamma rays of 59.5 and 123.6 keV, respectively | V, Mn, Zn, Tc, Ru, Cd, Xe, Cs, Ba, Hg and Rn (high-purity powder samples)  | Si(Li) detector with FWHM resolution of 160 eV at 5.9 keV                     |

|      |  |   |   |  |
|------|--|---|---|--|
| [53] | $K\alpha_2/K\alpha_1$ ,<br>$K\beta_{1,3}/K\alpha_1$ et<br>$K\beta_2/K\alpha_1$                               | 123.6 keV photons produced from a $^{57}\text{Co}$ annular radioactive source with an activity of 925 MBq   | Z=65-92 (powdered samples)  | Si(Li) detector with FWHM resolution of 160 eV at 5.9 keV              |
| [82] | $K\alpha_2/K\alpha_1$ ,<br>$K\beta'_1/K\alpha_1$<br>& $K\beta'_2/K\alpha_1$                                  | 59.537 keV photons produced from a $^{241}\text{Am}$ radioactive source   | Cr, Fe, Co, Ni, Cu, Zn, Br, Nb, Ba, Nd, Sm, Eu, Gd, Dy and Ho (Cr, Fe, Co, Ni, Cu, Zn, Gd and Dy were in sheet form, while KBr, $\text{Nb}_2\text{O}_5$ , BaO, $\text{Nd}_2\text{O}_3$ , $\text{SmCl}_3$ , $\text{EuCl}_2$ , $\text{HoCl}_3$ were in powder form) | Si(Li) detector with a resolution of 204 eV at 5.9 keV                 |
| [83] | $K\alpha_2/$<br>$K\alpha_1$ , $K\beta'_1/$<br>$K\alpha_1$ , $K\beta'_1/$<br>$K\alpha_2$ , $K\beta/K\alpha$   | 59.5 keV and 123.6 keV gamma rays emitted by a $^{241}\text{Am}$ annular radioactive source and a $^{57}\text{Co}$ annular radioactive source, respectively | Au, AuCl, $\text{Au}_2\text{O}_3$ and $\text{AuBr}_3$ (powdered samples of pure Au and its compounds)   | Ultra-LEGe detector with a resolution of 150 eV to 5.9 keV             |
| [38] | $K\beta/K\alpha$ ,<br>$K\beta'_1/K\alpha_1$ ,<br>& $K\beta'_2/K\alpha_1$                                     | 123.6 keV of gamma rays emitted by a weak source of $^{57}\text{Co}$ activity of 925 MBq  | Z = 73-81 (powdered samples of pure elements and their compounds)   | Ultra-LEGe detector with a resolution of 150 eV at 5.96 keV            |
| [84] | $K\alpha_2/$ , $K\alpha_1$<br>$K\beta_1/$ , $K\alpha_1$<br>& $K\beta/K\alpha$                                | Internal conversion of $^{203}\text{Hg}$ and $^{137}\text{Cs}$  | Tl and Ba   | Si(Li)   |
| [46] | $K\alpha_2/$ , $K\alpha_1$<br>$K\beta_2/$ , $K\alpha_1$<br>$K\beta'_1/$ , $K\alpha_1$<br>& $K\beta/K\alpha$  | 123.6 keV photons produced from a weak $^{57}\text{Co}$ radioactive source with activity of ~104 Bq   | Pt, Au and Pb (thin sheets of pure elements)  | HPGe detector with a resolution of 200 eV at 5.9 keV                   |
| [85] | $K\alpha_2/$ , $K\alpha_1$<br>$K\beta'_1/$ , $K\alpha_1$<br>& $K\beta/K\alpha$                               | Internal conversion decay of sources of $^{137}\text{Cs}$ and $^{203}\text{Hg}$ of ~2 $\mu\text{Ci}$ activity   | Ba and Tl   | Si(Li) detector with a resolution of 140 eV to 5.9 keV                 |
| [86] | $K\alpha_2/K\alpha_1$  | X-ray tube consisting of an Rh anode operating at 40 kV and 70 mA   | Zn (High Purity Metal Foil)   | Double Crystal Spectrometer  |
| [87] | $K\alpha_2/$ , $K\alpha_1$<br>$K\beta'_1/$ , $K\alpha_1$<br>$K\beta'_2/$ , $K\alpha_1$<br>& $K\beta/K\alpha$ | 59.5 keV photons from a $^{241}\text{Am}$ annular radioactive source with an activity of 100 mCi  | La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy and Er (spectroscopically pure targets of various thicknesses)   | Si(Li) detector with FWHM resolution of 160 eV at 5.96 keV             |
| [88] | $K\beta/K\alpha$<br>& $K\beta_{1,3}/$<br>$K\alpha_{1,2}$   | Photons with incident energies ranging from 3.75 keV to 30 keV  | Ni (high-purity metal foils)  | Bragg diffraction. The monochromator contains a double crystal Si(111) |

|      |   |   |   |   |
|------|---|---|---|---|
| [47] | $K\alpha_2/K\alpha_1$ ,<br>$K\beta'_1/$<br>$K\alpha_1$ , & $K\beta_2/$<br>$K\alpha_1$ | Gamma rays with energies of 59.54 keV and 100.934 keV produced from an annular radioactive source of $^{241}\text{Am}$ with an activity of $\sim 185$ GBq | Lu, W, Hg, Ti, and Pb ( $\text{PbO}$ , $\text{HgCl}_2$ , $\text{Lu}_2\text{O}_3$ , $\text{TlCl}_3 \cdot 4\text{H}_2\text{O}$ , and $\text{WCl}_4$ in powder form) | Energy Dispersive X-ray Fluorescence Spectrometer and HPGe Detector with a resolution of $\sim 182$ eV at 5.9 keV |
| [89] | $K\alpha_2/K\alpha_1$<br>& $K\beta_3/K\beta_1$  | X-ray generator consisting of an Rh anode operating at 40 kV and 60 mA  | Se, Y and Zr (high purity metal powder for Se, metal plates for Y and metal foils for Zr)   | Antiparallel Double Crystal X-ray Spectrometer  |
| [19] | $K\alpha_2/K\alpha_1$<br>& $K\beta/K\alpha$   | Primary x-rays were produced with a Rh-target x-ray tube under operating conditions of 40 kV and 60 mA  | $\text{CaF}_2$ crystal powder for Ca, foils for Sc, V, Co, and Ni, plates for Mg, Al, Ti, Mn, Fe, and Cu, and wafer for Si  | RIGAKU double-crystal spectrometer (System 3580E)   |

**Table 2.** Summary of the experimental  $K\alpha_2/K\alpha_1$  intensity ratios from  $^{13}\text{Al}$  to  $^{99}\text{Es}$  according to their target atomic numbers. The references from which the databases are extracted, the combined standard deviation  $z_i$ , the average  $z$ -score  $\bar{z}$ , the ratio  $S$ , and the weighted average values  $(K\alpha_2/K\alpha_1)_W$  are also listed.

| Z, Element | References | $K\alpha_2/K\alpha_1 \pm \Delta (K\alpha_2/K\alpha_1)$ | $(K\alpha_2/K\alpha_1)_W \pm \varepsilon$ | $z_i$ | $\bar{z}$ | $S$  |
|------------|------------|--|---|-------|-----------|------|
| Z=13, Al   | [77]       | 0.53±0.23  | 0.53±0.23                                 | 0     | 0         | 1.00 |
| Z=14, Si   | [77]       | 0.50±0.13  | 0.5112±0.0018                             | -0.09 | 0.68      | 0.98 |
|            | [19]       | 0.5071±0.0021  |   | -1.49 |           | 0.99 |
|            | [19]       | 0.5144±0.0055  |   | 0.55  |           | 1.01 |
|            | [19]       | 0.5304±0.0048  |   | -3.74 |           | 1.04 |
| Z=16, S    | [77]       | 0.52±0.084   | 0.4921±0.0027                             | 0.33  | 0.16      | 1.06 |
|            | [78]       | 0.4921±0.0027  |   | -0.01 |           | 1.00 |
| Z=21, Sc   | [36]       | 0.507±0.010  | 0.507±0.010                               | 0     | 0         | 1.00 |
| Z=22, Ti   | [36]       | 0.502±0.010  | 0.502±0.010                               | 0     | 0         | 1.00 |
| Z=23, V    | [36]       | 0.507±0.010  | 0.5066±0.0087                             | 0.03  | -0.02     | 1.00 |
|            | [81]       | 0.5026±0.0251  |   | -0.15 |           | 0.99 |
|            | [81]       | 0.5084±0.0254  |   | 0.07  |           | 1.00 |
| Z=24, Cr   | [36]       | 0.505±0.010  | 0.5047±0.0083                             | 0.02  | -0.01     | 1.00 |
|            | [82]       | 0.504±0.015  |   | -0.04 |           | 1.00 |
| Z=25, Mn   | [36]       | 0.500±0.010  | 0.5025±0.0083                             | -0.19 | 0.10      | 1.00 |
|            | [37]       | 0.51±0.026   |   | 0.28  |           | 1.01 |
|            | [81]       | 0.5063±0.0253  |   | 0.14  |           | 1.01 |
|            | [81]       | 0.5074±0.0254  |   | 0.18  |           | 1.01 |
| Z=26, Fe   | [36]       | 0.506±0.010  | 0.5066±0.0062                             | -0.05 | 0.02      | 1.00 |
|            | [41]       | 0.507±0.010  |   | 0.03  |           | 1.00 |
|            | [37]       | 0.51±0.026   |   | 0.13  |           | 1.01 |
|            | [82]       | 0.506±0.015  |   | -0.14 |           | 1.01 |
| Z=27, Co   | [36]       | 0.502±0.010  | 0.5059±0.0079                             | -0.31 | 0.15      | 0.99 |
|            | [37]       | 0.52±0.026   |   | 0.52  |           | 1.03 |
|            | [82]       | 0.510±0.015  |   | 0.24  |           | 1.01 |
| Z=28, Ni   | [36]       | 0.507±0.010  | 0.5120±0.052                              | -0.44 | -0.03     | 0.99 |
|            | [37]       | 0.52±0.026   |   | 0.30  |           | 1.02 |
|            | [82]       | 0.507±0.015  |   | -0.32 |           | 0.99 |
|            | [88]       | 0.515±0.007  |   | 0.34  |           | 1.01 |
| Z=29, Cu   | [36]       | 0.507±0.010  | 0.5096±0.0062                             | -0.22 | 0.06      | 0.99 |
|            | [41]       | 0.511±0.010  |   | 0.12  |           | 1.00 |
|            | [37]       | 0.52±0.026   |   | 0.39  |           | 1.02 |
|            | [82]       | 0.509±0.015  |   | -0.04 |           | 1.00 |
| Z=30, Zn   | [36]       | 0.513±0.010  | 0.5074±0.0018                             | 0.55  | 0.24      | 1.01 |
|            | [81]       | 0.5114±0.0256  |   | 0.16  |           | 1.01 |
|            | [81]       | 0.5177±0.0259  |   | 0.40  |           | 1.02 |
|            | [82]       | 0.511±0.015  |   | 0.24  |           | 1.01 |
|            | [86]       | 0.5071±0.0018  |   | -0.12 |           | 1.00 |
| Z=32, Ge   | [36]       | 0.512±0.010  | 0.5333±0.0013                             | -2.11 | -1.19     | 0.96 |
|            | [41]       | 0.506±0.010  |   | -2.70 |           | 0.95 |
|            | [19]       | 0.5086±0.0025  |   | -8.72 |           | 0.95 |
|            | [19]       | 0.5291±0.0025  |   | -1.48 |           | 0.99 |
|            | [19]       | 0.5558±0.0021  |   | 9.06  |           | 1.04 |
| Z=34, Se   | [41]       | 0.523±0.011  | 0.5180±0.0020                             | 0.45  | 0.2       | 1.01 |
|            | [89]       | 0.5178±0.0020  |   | -0.06 |           | 1.00 |
| Z=35, Br   | [82]       | 0.523±0.016  | 0.523±0.016                               | 0     | 0         | 1.00 |
| Z=37, Rb   | [41]       | 0.510±0.010  | 0.510±0.010                               | 0     | 0         | 1.00 |
| Z=38, Sr   | [36]       | 0.521±0.010  | 0.521±0.010                               | 0     | 0         | 1.00 |
| Z=39, Y    | [36]       | 0.523±0.010  | 0.5223±0.0022                             | 0.07  | 0.03      | 1.00 |
|            | [89]       | 0.5223±0.0023  |   | -0.02 |           | 1.00 |
| Z=40, Zr   | [36]       | 0.524±0.010  | 0.5251±0.0025                             | -0.11 | 0.08      | 1.00 |
|            | [41]       | 0.523±0.011  |   | -0.19 |           | 1.00 |
|            | [89]       | 0.5253±0.0027  |   | 0.08  |           | 1.00 |
| Z=41, Nb   | [36]       | 0.526±0.011  | 0.5276±0.0091                             | -0.11 | 0.04      | 1    |
|            | [82]       | 0.531±0.016  |   | 0.18  |           | 1.01 |
| Z=42, Mo   | [36]       | 0.525±0.011  | 0.5265±0.0078                             | -0.11 | 0         | 1.00 |
|            | [41]       | 0.528±0.011  |   | 0.11  |           | 1.00 |
| Z=43, Tc   | [81]       | 0.5280±0.0264  | 0.5305±0.0188                             | -0.08 | 0         | 1.00 |

|          |      |               |               |       |       |      |
|----------|------|---------------|---------------|-------|-------|------|
|          | [81] | 0.5330±0.0267 |               | 0.08  |       | 1    |
| Z=44, Ru | [81] | 0.5253±0.0263 | 0.5291±0.0187 | -0.12 | 0     | 0.99 |
|          | [81] | 0.5331±0.0267 |               | 0.12  |       | 1.01 |
| Z=45, Rh | [36] | 0.525±0.011   | 0.5220±0.0078 | 0.22  | 0     | 1.01 |
|          | [41] | 0.519±0.011   |               | -0.22 |       | 0.99 |
| Z=46, Pd | [36] | 0.526±0.011   | 0.526±0.011   | 0     | 0     | 1.00 |
| Z=47, Ag | [36] | 0.522±0.010   | 0.522±0.0068  | -0.02 | -0.03 | 1.00 |
|          | [41] | 0.524±0.011   |               | 0.14  |       | 1.00 |
|          | [74] | 0.518±0.018   |               | -0.22 |       | 0.99 |
| Z=48, Cd | [36] | 0.544±0.011   | 0.5405±0.0095 | 0.24  | -0.16 | 1.01 |
|          | [81] | 0.5277±0.0264 |               | -0.46 |       | 0.98 |
|          | [81] | 0.5329±0.0266 |               | -0.27 |       | 0.99 |
| Z=49, In | [36] | 0.539±0.011   | 0.5341±0.0074 | 0.37  | 0.02  | 1.01 |
|          | [74] | 0.530±0.010   |               | -0.33 |       | 0.99 |
| Z=50, Sn | [36] | 0.541±0.011   | 0.5360±0.0078 | 0.37  | 0     | 1.01 |
|          | [41] | 0.531±0.011   |               | -0.37 |       | 0.99 |
| Z=51, Sb | [56] | 0.517±0.021   | 0.517±0.021   | 0     | 0     | 1.00 |
| Z=52, Te | [56] | 0.527±0.021   | 0.5142±0.0063 | 0.58  | 0.1   | 1.02 |
|          | [69] | 0.509±0.010   |               | -0.44 |       | 0.99 |
|          | [51] | 0.516±0.0089  |               | 0.17  |       | 1.00 |
| Z=53, I  | [56] | 0.536±0.021   | 0.5277±0.0063 | 0.38  | 0.2   | 1.02 |
|          | [41] | 0.541±0.011   |               | 1.05  |       | 1.03 |
|          | [51] | 0.519±0.0082  |               | -0.84 |       | 0.98 |
| Z=54, Xe | [81] | 0.5322±0.0266 | 0.5352±0.0189 | -0.09 | 0     | 0.99 |
|          | [81] | 0.5383±0.0269 |               | 0.09  |       | 1.01 |
| Z=55, Cs | [56] | 0.540±0.022   | 0.5361±0.0046 | 0.17  | -0.01 | 1.01 |
|          | [69] | 0.522±0.009   |               | -1.39 |       | 0.97 |
|          | [51] | 0.542±0.0062  |               | 0.76  |       | 1.01 |
|          | [44] | 0.540±0.032   |               | 0.12  |       | 1.01 |
|          | [81] | 0.5376±0.0269 |               | 0.06  |       | 1.00 |
|          | [81] | 0.5411±0.0271 |               | 0.18  |       | 1.01 |
|          | [81] | 0.5310±0.0266 |               | -0.19 |       | 0.99 |
|          | [81] | 0.5411±0.0271 |               | 0.18  |       | 1.01 |
| Z=56, Ba | [56] | 0.562 ±0.023  | 0.5426±0.0046 | 0.83  | -0.03 | 1.04 |
|          | [41] | 0.533±0.011   |               | -0.80 |       | 0.98 |
|          | [69] | 0.541±0.009   |               | -0.16 |       | 1.00 |
|          | [51] | 0.548±0.0073  |               | 0.6   |       | 1.01 |
|          | [81] | 0.5319±0.0266 |               | -0.40 |       | 0.98 |
|          | [81] | 0.5463±0.0273 |               | 0.13  |       | 1.01 |
|          | [82] | 0.535±0.016   |               | -0.46 |       | 0.99 |
| Z=57, La | [56] | 0.564±0.023   | 0.5627±0.0066 | 0.05  | 0.34  | 1.00 |
|          | [51] | 0.553±0.0080  |               | -0.93 |       | 0.98 |
|          | [87] | 0.592±0.014   |               | 1.89  |       | 1.05 |
| Z=58, Ce | [56] | 0.508±0.020   | 0.5465±0.0052 | -1.86 | -0.48 | 0.93 |
|          | [41] | 0.536±0.011   |               | -0.86 |       | 0.98 |
|          | [51] | 0.557±0.0070  |               | 1.21  |       | 1.02 |
|          | [87] | 0.541±0.013   |               | -0.39 |       | 0.99 |
| Z=59, Pr | [56] | 0.530±0.021   | 0.5584±0.0104 | -1.21 | -0.05 | 0.95 |
|          | [51] | 0.569±0.019   |               | 0.49  |       | 1.02 |
|          | [44] | 0.543±0.024   |               | -0.59 |       | 0.97 |
|          | [87] | 0.583±0.020   |               | 1.09  |       | 1.04 |
| Z=60, Nd | [56] | 0.532±0.021   | 0.5446±0.0043 | -0.59 | 0.00  | 0.98 |
|          | [51] | 0.573±0.015   |               | 1.082 |       | 1.05 |
|          | [76] | 0.552±0.031   |               | 0.23  |       | 1.01 |
|          | [44] | 0.548±0.018   |               | 0.18  |       | 1.01 |
|          | [52] | 0.57±0.053    |               | 0.48  |       | 1.05 |
|          | [80] | 0.546 ±0.006  |               | 0.18  |       | 1.00 |
|          | [80] | 0.527 ±0.015  |               | -1.13 |       | 0.97 |
|          | [80] | 0.527 ±0.015  |               | -1.13 |       | 0.97 |
|          | [82] | 0.541±0.016   |               | -0.22 |       | 0.99 |
|          | [87] | 0.548±0.019   |               | 0.17  |       | 1.01 |
| Z=62, Sm | [56] | 0.540±0.022   | 0.5516±0.0047 | -0.52 | -0.09 | 0.98 |
|          | [41] | 0.560±0.011   |               | 0.70  |       | 1.02 |
|          | [67] | 0.5542±0.0075 |               | 0.29  |       | 1.00 |
|          | [51] | 0.569±0.028   |               | 0.61  |       | 1.03 |
|          | [76] | 0.550±0.024   |               | -0.07 |       | 1.00 |

|          |  |   |               |   |       |  |
|----------|--|---|---------------|---|-------|--|
|          | [44]<br>[52]<br>[45]<br>[82]<br>[87]   | 0.550±0.012<br>0.56±0.052<br>0.54±0.030<br>0.549±0.017<br>0.526±0.018   |               | -0.13<br>0.16<br>-0.38<br>-0.15<br>-1.38  |       | 1.00<br>1.02<br>0.98<br>1.00<br>0.95   |
| Z=63, Eu | [56]<br>[69]<br>[76]<br>[52]<br>[45]<br>[80]<br>[80]<br>[80]<br>[82]<br>[87]                         | 0.549±0.022<br>0.552±0.009<br>0.552±0.026<br>0.57±0.052<br>0.56±0.031<br>0.548 ±0.015<br>0.538 ±0.003<br>0.538 ±0.003<br>0.551±0.017<br>0.504±0.017   | 0.5389±0.002  | 0.46<br>1.42<br>050<br>0.60<br>0.68<br>0.61<br>-0.30<br>-0.30<br>0.71<br>-2.05                          | 0.24  | 1.02<br>1.02<br>1.02<br>1.06<br>1.04<br>1.02<br>1.00<br>1.00<br>1.02<br>0.94                         |
| Z=64, Gd | [56]<br>[41]<br>[68]<br>[76]<br>[44]<br>[52]<br>[45]<br>[80]<br>[80]<br>[80]<br>[82]<br>[87]         | 0.569±0.023<br>0.550±0.011<br>0.517±0.022<br>0.553±0.027<br>0.553±0.028<br>0.56±0.052<br>0.58±0.032<br>0.528 ±0.005<br>0.506 ±0.006<br>0.507 ±0.006<br>0.553±0.017<br>0.539±0.020                   | 0.5219±0.0029 | 2.03<br>2.47<br>-0.22<br>1.14<br>1.10<br>0.73<br>1.81<br>1.05<br>-2.39<br>-2.24<br>1.80<br>0.84         | 0.68  | 1.09<br>1.05<br>0.99<br>1.06<br>1.06<br>1.07<br>1.11<br>1.01<br>0.97<br>0.97<br>1.06<br>1.03         |
| Z=65, Tb | [56]<br>[44]<br>[53]<br>[87]   | 0.562±0.023<br>0.555±0.030<br>0.543±0.026<br>0.578±0.023  | 0.5611±0.0125 | 0.03<br>-0.19<br>-0.63<br>0.64  | -0.03 | 1.00<br>0.99<br>0.97<br>1.03   |
| Z=66, Dy | [56]<br>[60]<br>[76]<br>[44]<br>[52]<br>[45]<br>[80]<br>[80]<br>[80]<br>[53]<br>[82]<br>[87]         | 0.551±0.022<br>0.54±0.05<br>0.556±0.021<br>0.558±0.014<br>0.56±0.052<br>0.62±0.034<br>0.537 ±0.030<br>0.516 ±0.003<br>0.516 ±0.003<br>0.557±0.027<br>0.556±0.017<br>0.573±0.026                     | 0.5193±0.002  | 1.43<br>0.41<br>1.74<br>2.74<br>0.78<br>2.96<br>0.59<br>-0.91<br>-0.91<br>1.39<br>2.14<br>2.06          | 1.20  | 1.06<br>1.04<br>1.07<br>1.07<br>1.08<br>1.19<br>1.03<br>0.99<br>0.99<br>1.07<br>1.07<br>1.10         |
| Z=67, Ho | [56]<br>[41]<br>[63]<br>[65]<br>[67]<br>[76]<br>[44]<br>[45]<br>[80]<br>[80]<br>[80]<br>[53]<br>[82] | 0.560±0.022<br>0.564±0.011<br>0.576±0.019<br>0.568±0.005<br>0.5586±0.0030<br>0.558±0.018<br>0.561±0.028<br>0.58±0.032<br>0.559 ±0.013<br>0.554 ±0.004<br>0.554 ±0.004<br>0.565±0.026<br>0.560±0.017 | 0.5584±0.0018 | 0.70<br>0.50<br>0.92<br>1.81<br>0.06<br>-0.02<br>0.09<br>0.67<br>0.05<br>-1.00<br>-1.00<br>0.25<br>0.09 | 0.19  | 1.00<br>1.01<br>1.03<br>1.02<br>1.00<br>1.00<br>1.00<br>1.04<br>1.00<br>0.99<br>0.99<br>1.01<br>1.00 |
| Z=68, Er | [56]<br>[72]<br>[73]<br>[76]<br>[44]<br>[52]<br>[45]<br>[53]<br>[87]                                 | 0.522±0.021<br>0.595±0.015<br>0.564±0.027<br>0.560±0.025<br>0.562±0.040<br>0.60±0.055<br>0.57±0.031<br>0.551±0.026<br>0.530±0.023   | 0.5620±0.0082 | -1.77<br>1.93<br>0.07<br>-0.08<br>0.00<br>0.68<br>0.25<br>-0.40<br>-1.31                                | -0.07 | 0.93<br>1.06<br>1.00<br>1.00<br>1.00<br>1.07<br>1.01<br>0.98<br>0.94                                 |
| Z=69, Tm | [56]<br>[48]   | 0.576±0.023<br>0.51±0.01  | 0.5630±0.0025 | 0.56<br>-5.14   | -0.38 | 1.02<br>0.91   |

|          |      |               |               |       |       |      |
|----------|------|---------------|---------------|-------|-------|------|
|          | [63] | 0.570±0.018   |               | 0.38  |       | 1.01 |
|          | [65] | 0.565±0.007   |               | 0.27  |       | 1.00 |
|          | [67] | 0.5681±0.0031 |               | 1.28  |       | 1.01 |
|          | [68] | 0.5728±0.0116 |               | 0.83  |       | 1.02 |
|          | [69] | 0.551±0.009   |               | -1.29 |       | 0.98 |
|          | [75] | 0.561±0.028   |               | -0.07 |       | 1.00 |
|          | [53] | 0.558±0.025   |               | -0.20 |       | 0.99 |
| Z=70, Yb | [56] | 0.587±0.024   | 0.5747±0.0019 | 0.51  | -0.31 | 1.02 |
|          | [41] | 0.569±0.011   |               | -0.51 |       | 0.99 |
|          | [64] | 0.576 ± 0.002 |               | 0.47  |       | 1.00 |
|          | [69] | 0.560±0.009   |               | -1.60 |       | 0.97 |
|          | [70] | 0.554±0.014   |               | -1.47 |       | 0.96 |
|          | [75] | 0.561±0.033   |               | -0.41 |       | 0.98 |
|          | [76] | 0.563±0.021   |               | -0.56 |       | 0.98 |
|          | [52] | 0.56±0.052    |               | -0.28 |       | 0.97 |
|          | [53] | 0.608±0.031   |               | 1.07  |       | 1.06 |
| Z=71, Lu | [56] | 0.585±0.023   | 0.5701±0.0026 | 0.64  | 0.18  | 1.03 |
|          | [63] | 0.585±0.023   |               | 0.64  |       | 1.03 |
|          | [67] | 0.5698±0.0027 |               | -0.07 |       | 1.00 |
|          | [75] | 0.566±0.031   |               | -0.13 |       | 0.99 |
|          | [53] | 0.602±0.031   |               | 1.03  |       | 1.06 |
|          | [47] | 0.547±0.022   |               | -1.04 |       | 0.96 |
| Z=72, Hf | [56] | 0.571±0.023   | 0.5809±0.0092 | -0.43 | -0.01 | 0.98 |
|          | [70] | 0.582±0.012   |               | 0.09  |       | 1.00 |
|          | [79] | 0.580±0.0261  |               | -0.03 |       | 1.00 |
|          | [53] | 0.589±0.026   |               | 0.31  |       | 1.01 |
| Z=73, Ta | [56] | 0.554±0.022   | 0.5753±0.0027 | 0.12  | -0.23 | 1.00 |
|          | [59] | 0.625±0.031   |               | -0.33 |       | 0.99 |
|          | [41] | 0.575±0.011   |               | 0.20  |       | 1.00 |
|          | [64] | 0.582 ± 0.002 |               | -0.95 |       | 0.94 |
|          | [67] | 0.5708±0.0027 |               | -0.05 |       | 1.00 |
|          | [69] | 0.571±0.009   |               | -0.17 |       | 0.99 |
|          | [75] | 0.573±0.023   |               | 1.26  |       | 1.07 |
|          | [76] | 0.570±0.023   |               | -0.38 |       | 0.95 |
|          | [53] | 0.601±0.031   |               | -1.37 |       | 0.95 |
| Z=74, W  | [56] | 0.578±0.023   | 0.5753±0.0027 | 0.12  | -0.23 | 1.00 |
|          | [63] | 0.568±0.022   |               | -0.33 |       | 0.99 |
|          | [67] | 0.5761±0.0028 |               | 0.20  |       | 1.00 |
|          | [50] | 0.543±0.034   |               | -0.95 |       | 0.94 |
|          | [75] | 0.574±0.029   |               | -0.05 |       | 1.00 |
|          | [76] | 0.572±0.020   |               | -0.17 |       | 0.99 |
|          | [53] | 0.617±0.033   |               | 1.26  |       | 1.07 |
|          | [38] | 0.548±0.033   |               | -0.83 |       | 0.95 |
|          | [47] | 0.545±0.022   |               | -1.37 |       | 0.95 |
| Z=75, Re | [56] | 0.587±0.024   | 0.5910±0.0143 | -0.14 | 0.06  | 0.99 |
|          | [75] | 0.580±0.026   |               | -0.37 |       | 0.98 |
|          | [53] | 0.599±0.033   |               | 0.22  |       | 1.01 |
|          | [38] | 0.613±0.037   |               | 0.55  |       | 1.04 |
| Z=76, Os | [56] | 0.602±0.024   | 0.5777±0.0093 | 0.94  | 0.35  | 1.04 |
|          | [68] | 0.569±0.011   |               | -0.60 |       | 0.98 |
|          | [53] | 0.619±0.037   |               | 1.08  |       | 1.07 |
|          | [38] | 0.577±0.035   |               | -0.02 |       | 1.00 |
| Z=77, Ir | [56] | 0.577±0.023   | 0.5786±0.0095 | -0.06 | 0.05  | 1.00 |
|          | [41] | 0.578±0.011   |               | -0.04 |       | 1.00 |
|          | [53] | 0.588±0.035   |               | 0.26  |       | 1.02 |
| Z=78, Pt | [56] | 0.563±0.028   | 0.5854±0.0035 | -0.80 | -0.21 | 0.96 |
|          | [64] | 0.591±0.005   |               | 0.92  |       | 1.01 |
|          | [68] | 0.575±0.0077  |               | -1.24 |       | 0.98 |
|          | [69] | 0.577±0.009   |               | -0.87 |       | 0.99 |
|          | [53] | 0.574±0.02    |               | -0.56 |       | 0.98 |
|          | [38] | 0.584±0.035   |               | -0.04 |       | 1.00 |
|          | [46] | 0.597±0.010   |               | 1.09  |       | 1.02 |
| Z=79, Au | [56] | 0.585±0.029   | 0.5875±0.0021 | -0.09 | -0.04 | 1.00 |
|          | [59] | 0.625±0.031   |               | 1.21  |       | 1.06 |
|          | [49] | 0.57±0.03     |               | -0.58 |       | 0.97 |
|          | [41] | 0.584±0.012   |               | -0.29 |       | 0.99 |
|          | [60] | 0.60±0.03     |               | 0.42  |       | 1.02 |

|          |      |               |               |       |       |      |
|----------|------|---------------|---------------|-------|-------|------|
|          | [63] | 0.575±0.020   |               | -0.62 |       | 0.98 |
|          | [65] | 0.582±0.026   |               | -0.21 |       | 0.99 |
|          | [67] | 0.5862±0.0026 |               | -0.38 |       | 1.00 |
|          | [50] | 0.553±0.035   |               | -0.98 |       | 0.94 |
|          | [43] | 0.5921±0.0041 |               | 1.01  |       | 1.01 |
|          | [75] | 0.581±0.029   |               | -0.22 |       | 0.99 |
|          | [53] | 0.591±0.032   |               | 0.11  |       | 1.01 |
|          | [83] | 0.6015±0.030  |               | -0.47 |       | 1.02 |
|          | [46] | 0.583±0.011   |               | -0.40 |       | 0.99 |
| Z=80, Hg | [56] | 0.595±0.030   | 0.5919±0.0036 | 0.10  | -0.05 | 1.01 |
|          | [49] | 0.58±0.03     |               | -0.39 |       | 0.98 |
|          | [43] | 0.5933±0.0041 |               | 0.25  |       | 1.00 |
|          | [75] | 0.586±0.024   |               | -0.24 |       | 0.99 |
|          | [73] | 0.579±0.024   |               | -0.53 |       | 0.98 |
|          | [73] | 0.579±0.016   |               | -0.79 |       | 0.98 |
|          | [76] | 0.588±0.018   |               | -0.21 |       | 0.99 |
|          | [81] | 0.5792±0.0290 |               | -0.44 |       | 0.98 |
|          | [81] | 0.5921±0.0296 |               | 0.01  |       | 1.00 |
|          | [53] | 0.665±0.041   |               | 1.78  |       | 1.12 |
|          | [47] | 0.589±0.024   |               | -0.12 |       | 1.00 |
| Z=81, Tl | [56] | 0.574±0.029   | 0.5942±0.0030 | -0.69 | -0.04 | 0.97 |
|          | [58] | 0.580±0.030   |               | -0.47 |       | 0.98 |
|          | [49] | 0.585±0.025   |               | -0.36 |       | 0.98 |
|          | [62] | 0.589±0.008   |               | -0.60 |       | 0.99 |
|          | [69] | 0.600±0.009   |               | 0.62  |       | 1.01 |
|          | [71] | 0.592±0.013   |               | -0.16 |       | 1.00 |
|          | [50] | 0.562±0.035   |               | -0.92 |       | 0.95 |
|          | [43] | 0.5925±0.0041 |               | -0.33 |       | 1.00 |
|          | [75] | 0.587±0.036   |               | -0.20 |       | 0.99 |
|          | [53] | 0.637±0.032   |               | 1.33  |       | 1.07 |
|          | [84] | 0.609±0.041   |               | 0.36  |       | 1.02 |
|          | [85] | 0.609±0.009   |               | 1.57  |       | 1.02 |
|          | [47] | 0.579±0.023   |               | -0.65 |       | 0.97 |
| Z=82, Pb | [56] | 0.596±0.030   | 0.5946±0.0015 | 0.05  | -0.04 | 1.00 |
|          | [58] | 0.588 ±0.030  |               | -0.22 |       | 0.99 |
|          | [49] | 0.59±0.03     |               | -0.15 |       | 0.99 |
|          | [41] | 0.589±0.012   |               | -0.47 |       | 0.99 |
|          | [64] | 0.597±0.003   |               | 0.70  |       | 1.00 |
|          | [65] | 0.592±0.003   |               | -0.79 |       | 1.00 |
|          | [67] | 0.5938±0.0026 |               | -0.28 |       | 1.00 |
|          | [50] | 0.583±0.037   |               | -0.31 |       | 0.98 |
|          | [43] | 0.5984±0.0042 |               | 0.84  |       | 1.01 |
|          | [75] | 0.589±0.020   |               | -0.28 |       | 0.99 |
|          | [76] | 0.593±0.019   |               | -0.09 |       | 1.00 |
|          | [53] | 0.606±0.042   |               | 0.27  |       | 1.02 |
|          | [46] | 0.596±0.010   |               | 0.13  |       | 1.00 |
|          | [47] | 0.595±0.024   |               | 0.01  |       | 1.00 |
| Z=83, Bi | [56] | 0.599±0.030   | 0.6084±0.0049 | -0.31 | -0.16 | 0.98 |
|          | [59] | 0.667±0.033   |               | 1.76  |       | 1.10 |
|          | [49] | 0.593±0.025   |               | -0.60 |       | 0.97 |
|          | [41] | 0.596±0.012   |               | -0.96 |       | 0.98 |
|          | [65] | 0.613±0.006   |               | 0.59  |       | 1.01 |
|          | [50] | 0.582±0.037   |               | -0.71 |       | 0.96 |
|          | [75] | 0.594±0.022   |               | -0.64 |       | 0.98 |
|          | [53] | 0.590±0.041   |               | -0.45 |       | 0.97 |
| Z=86, Rn | [49] | 0.598±0.025   | 0.5992±0.0162 | -0.04 | 0.02  | 1.00 |
|          | [81] | 0.5837±0.0292 |               | -0.46 |       | 0.97 |
|          | [81] | 0.6183±0.0309 |               | 0.55  |       | 1.03 |
| Z=88, Ra | [49] | 0.593±0.025   | 0.593±0.025   | 0     | 0     | 1.00 |
| Z=90, Th | [56] | 0.610±0.031   | 0.6118±0.0068 | -0.06 | -0.01 | 1.00 |
|          | [49] | 0.598±0.025   |               | -0.53 |       | 0.98 |
|          | [41] | 0.617±0.012   |               | 0.38  |       | 1.01 |
|          | [66] | 0.61±0.010    |               | -0.15 |       | 1.00 |
|          | [50] | 0.605±0.033   |               | -0.20 |       | 0.99 |
|          | [75] | 0.622±0.041   |               | 0.25  |       | 1.02 |
|          | [53] | 0.624±0.044   |               | 0.27  |       | 1.02 |
| Z=91, Pa | [66] | 0.62±0.010    | 0.62±0.010    | 0     | 0     | 1.00 |

|          |      |             |               |       |       |      |
|----------|------|-------------|---------------|-------|-------|------|
| Z=92, U  | [56] | 0.610±0.031 | 0.6182±0.0051 | -0.26 | 0.10  | 0.99 |
|          | [49] | 0.608±0.022 |               | -0.45 |       | 0.98 |
|          | [41] | 0.633±0.012 |               | 1.13  |       | 1.02 |
|          | [62] | 0.611±0.008 |               | -0.76 |       | 0.99 |
|          | [66] | 0.62±0.010  |               | 0.16  |       | 1.00 |
|          | [50] | 0.613±0.033 |               | -0.16 |       | 0.99 |
|          | [75] | 0.632±0.038 |               | 0.36  |       | 1.02 |
|          | [53] | 0.653±0.046 | 0.75          | 1.06  |       |      |
| Z=93, Np | [56] | 0.635±0.032 | 0.6304±0.0095 | 0.14  | 0.05  | 1.01 |
|          | [66] | 0.63±0.01   |               | -0.03 |       | 1.00 |
| Z=94, Pu | [56] | 0.630±0.032 | 0.6193±0.005  | 0.33  | 0.24  | 1.02 |
|          | [41] | 0.641±0.013 |               | 1.53  |       | 1.04 |
|          | [62] | 0.610±0.008 |               | -0.96 |       | 0.98 |
|          | [66] | 0.62±0.010  |               | 0.06  |       | 1.00 |
| Z=95, Am | [56] | 0.619±0.031 | 0.6290±0.0095 | -0.31 | -0.12 | 0.98 |
|          | [66] | 0.63±0.010  |               | 0.08  |       | 1.00 |
| Z=96, Cm | [57] | 0.626±0.006 | 0.6312±0.0035 | -0.75 | 0.16  | 0.99 |
|          | [61] | 0.632±0.006 |               | 0.11  |       | 1.00 |
|          | [62] | 0.627±0.008 |               | -0.48 |       | 0.99 |
|          | [66] | 0.65±0.010  |               | 1.77  |       | 1.03 |
| Z=97, Bk | [61] | 0.643±0.008 | 0.6301±0.0062 | 1.27  | -0.22 | 1.02 |
|          | [66] | 0.61±0.010  |               | -1.71 |       | 0.97 |
| Z=98, Cf | [61] | 0.657±0.008 | 0.6504±0.0062 | 0.65  | -0.11 | 1.01 |
|          | [66] | 0.64±0.010  |               | -0.88 |       | 0.98 |
| Z=99, Es | [61] | 0.666±0.011 | 0.666±0.011   | 0     | 0     | 1.00 |

**Table 3.** Summary of the experimental  $K\beta'_1/K\alpha_1$  intensity ratios from  $^{24}\text{Cr}$  to  $^{96}\text{Cm}$  according to their target atomic numbers. The references from which the databases are extracted, the combined standard deviation  $z_i$ , the average  $z$ -score  $\bar{z}$ , the ratio  $S$ , and the weighted average values  $(K\beta'_1/K\alpha_1)_W$  are also listed.

| Z, Element | References   | $K\beta'_1/K\alpha_1 \pm \Delta (K\beta'_1/K\alpha_1)$   | $(K\beta'_1/K\alpha_1)_W \pm \varepsilon$ | $z_i$   | $\bar{z}$ | $S$  |
|------------|--|--|---|---|-----------|--|
| Z=24, Cr   | [82]   | 0.176±0.0088   | 0.176±0.0088                              | 0   | 0         | 1.00   |
| Z=26, Fe   | [82]   | 0.180±0.0090   | 0.180±0.0090                              | 0   | 0         | 1.00   |
| Z=27, Co   | [82]   | 0.180±0.0090   | 0.180±0.0090                              | 0   | 0         | 1.00   |
| Z=28, Ni   | [82]   | 0.181±0.0091   | 0.181±0.0091                              | 0   | 0         | 1.00   |
| Z=29, Cu   | [82]   | 0.189±0.0095   | 0.189±0.0095                              | 0   | 0         | 1.00   |
| Z=30, Zn   | [82]   | 0.183±0.0092   | 0.183±0.0092                              | 0   | 0         | 1.00   |
| Z=35, Br   | [82]   | 0.213±0.011  | 0.213±0.011                               | 0   | 0         | 1.00   |
| Z=40, Zr   | [90]   | 0.252 ± 0.001  | 0.252 ± 0.001                             | 0   | 0         | 1.00   |
| Z=41, Nb   | [90]<br>[82]   | 0.258 ± 0.001<br>0.239±0.012   | 0.2579±0.001                              | 0.09<br>-1.57   | -0.74     | 1.00<br>0.93   |
| Z=42, Mo   | [90]   | 0.259 ± 0.001  | 0.259 ± 0.001                             | 0   | 0         | 1.00   |
| Z=44, Ru   | [90]   | 0.265 ± 0.002  | 0.265 ± 0.002                             | 0   | 0         | 1.00   |
| Z=45, Rh   | [90]   | 0.272 ± 0.002  | 0.272 ± 0.002                             | 0   | 0         | 1.00   |
| Z=46, Pd   | [90]   | 0.270 ± 0.003  | 0.270 ± 0.003                             | 0   | 0         | 1.00   |
| Z=47, Ag   | [74]<br>[90]   | 0.2745±0.0055<br>0.272 ± 0.003   | 0.2726±0.026                              | 0.32<br>-0.14   | 0.09      | 1.01<br>1.00   |
| Z=48, Cd   | [90]   | 0.273 ± 0.004  | 0.273 ± 0.004                             | 0   | 0         | 1.00   |
| Z=49, In   | [74]<br>[90]   | 0.2818±0.0028<br>0.279 ± 0.005   | 0.2811±0.0024                             | 0.18<br>-0.38   | 0.10      | 1.00<br>0.99   |
| Z=50, Sn   | [90]   | 0.283 ± 0.006  | 0.283 ± 0.006                             | 0   | 0         | 1.00   |
| Z=52, Te   | [69]   | 0.2833±0.0025  | 0.2833±0.0025                             | 0   | 0         | 1.00   |
| Z=55, Cs   | [74]<br>[44]   | 0.2919±0.0029<br>0.283±0.040   | 0.2919±0.0029                             | 0.01<br>-0.22   | -0.10     | 1.00<br>0.97   |
| Z=56, Ba   | [74]<br>[82]   | 0.2899±0.0029<br>0.289±0.014   | 0.2899±0.0028                             | 0.01<br>-0.06   | -0.03     | 1.00<br>1.00   |
| Z=57, La   | [87]   | 0.313±0.013  | 0.313±0.013                               | 0   | 0         | 1.00   |
| Z=58, Ce   | [87]   | 0.297 ± 0.010  | 0.297 ± 0.010                             | 0   | 0         | 1.00   |
| Z=59, Pr   | [44]<br>[87]   | 0.294±0.019<br>0.289 ± 0.009   | 0.2899±0.0081                             | 0.20<br>-0.08   | 0.06      | 1.01<br>1.00   |
| Z=60, Nd   | [44]<br>[80]<br>[80]<br>[80]<br>[82]<br>[87]         | 0.298±0.024<br>0.296 ± 0.006<br>0.295 ± 0.015<br>0.295 ± 0.015<br>0.302±0.015<br>0.280 ± 0.011               | 0.2938±0.0044                             | 0.17<br>0.29<br>0.07<br>0.07<br>0.52<br>-1.17           | -0.01     | 1.01<br>1.01<br>1.00<br>1.00<br>1.03<br>0.95         |
| Z=62, Sm   | [44]<br>[45]<br>[82]<br>[87]                         | 0.301±0.026<br>0.32±0.024<br>0.306±0.015<br>0.289 ± 0.011  | 0.2982±0.0079                             | 0.10<br>0.86<br>0.46<br>-0.68                           | 0.18      | 1.01<br>1.07<br>1.03<br>0.97                         |
| Z=63, Eu   | [45]<br>[80]<br>[80]<br>[80]<br>[82]<br>[87]         | 0.34±0.025<br>0.297 ± 0.015<br>0.298 ± 0.003<br>0.298 ± 0.003<br>0.312±0.015<br>0.297±0.012                  | 0.2985±0.0020                             | 1.65<br>-0.10<br>-0.14<br>-0.14<br>0.89<br>-0.12        | 0.34      | 1.14<br>0.99<br>1.00<br>1.00<br>1.05<br>0.99         |
| Z=64, Gd   | [44]<br>[45]<br>[80]<br>[80]<br>[80]<br>[82]<br>[87] | 0.306±0.042<br>0.36±0.027<br>0.305 ± 0.005<br>0.301 ± 0.006<br>0.301 ± 0.006<br>0.314±0.016<br>0.293 ± 0.012 | 0.3032±0.0030                             | 0.07<br>2.09<br>0.31<br>-0.33<br>-0.33<br>0.66<br>-0.82 | 0.24      | 1.01<br>1.19<br>1.01<br>0.99<br>0.99<br>1.04<br>0.97 |
| Z=65, Tb   | [44]<br>[87]   | 0.309±0.032<br>0.314±0.011   | 0.3135±0.0104                             | -0.13<br>0.03   | -0.05     | 0.99<br>1.00   |
| Z=66, Dy   | [44]<br>[45]<br>[80]<br>[80]                         | 0.310±0.019<br>0.39±0.029<br>0.334 ± 0.030<br>0.328 ± 0.003  | 0.3284±0.0021                             | -0.96<br>2.12<br>0.19<br>-0.11                          | 0.09      | 0.94<br>1.19<br>1.02<br>1.00                         |

|          |      |               |               |       |       |      |
|----------|------|---------------|---------------|-------|-------|------|
|          | [80] | 0.329 ±0.003  |               | 0.16  |       | 1.00 |
|          | [82] | 0.315±0.016   |               | -0.83 |       | 0.96 |
|          | [87] | 0.329 ±0.015  |               | 0.04  |       | 1.00 |
| Z=67, Ho | [63] | 0.329±0.016   | 0.3169±0.0022 | 0.75  | 0.40  | 1.04 |
|          | [65] | 0.310±0.004   |               | -1.51 |       | 0.98 |
|          | [44] | 0.312±0.018   |               | -0.27 |       | 0.98 |
|          | [45] | 0.40 ±0.030   |               | 2.76  |       | 1.26 |
|          | [80] | 0.319 ±0.013  |               | 0.16  |       | 1.01 |
|          | [80] | 0.319 ±0.004  |               | 0.46  |       | 1.01 |
|          | [80] | 0.319 ±0.004  |               | 0.46  |       | 1.01 |
|          | [82] | 0.323±0.015   |               | 0.40  |       | 1.02 |
| Z=68, Er | [72] | 0.309±0.0068  | 0.3155±0.0057 | -0.73 | 0.48  | 0.98 |
|          | [73] | 0.316±0.017   |               | 0.03  |       | 1.00 |
|          | [44] | 0.314±0.041   |               | -0.04 |       | 1.00 |
|          | [45] | 0.38±0.028    |               | 2.26  |       | 1.20 |
|          | [87] | 0.330 ±0.016  |               | 0.86  |       | 1.05 |
| Z=69, Tm | [63] | 0.335±0.017   | 0.3126±0.0046 | 1.27  | 0.59  | 1.07 |
|          | [65] | 0.309±0.005   |               | -0.53 |       | 0.99 |
|          | [53] | 0.330±0.016   |               | 1.04  |       | 1.06 |
| Z=71, Lu | [63] | 0.336±0.017   | 0.3390±0.0108 | -0.15 | -0.02 | 0.99 |
|          | [47] | 0.341±0.014   |               | 0.11  |       | 1.01 |
| Z=74, W  | [63] | 0.334±0.017   | 0.3407±0.0095 | -0.34 | -0.09 | 0.98 |
|          | [38] | 0.329±0.020   |               | -0.53 |       | 0.97 |
|          | [47] | 0.351±0.014   |               | 0.61  |       | 1.03 |
| Z=75, Re | [38] | 0.324±0.019   | 0.324±0.019   | 0     | 0     | 1.00 |
| Z=76, Os | [38] | 0.343±0.021   | 0.343±0.021   | 0     | 0     | 1.00 |
| Z=78, Pt | [38] | 0.322±0.019   | 0.3361±0.0088 | -0.67 | -0.19 | 0.96 |
|          | [46] | 0.340±0.010   |               | 0.29  |       | 1.01 |
| Z=79, Au | [49] | 0.32±0.03     | 0.3411±0.0060 | -0.69 | 0.02  | 0.94 |
|          | [63] | 0.342±0.021   |               | 0.04  |       | 1.00 |
|          | [65] | 0.336±0.017   |               | -0.28 |       | 0.99 |
|          | [43] | 0.341±0.010   |               | 0.00  |       | 1.00 |
|          | [83] | 0.3703±0.019  |               | 1.47  |       | 1.09 |
|          | [46] | 0.336±0.011   |               | -0.40 |       | 0.99 |
| Z=80, Hg | [49] | 0.336±0.031   | 0.3416±0.0028 | -0.18 | -0.13 | 0.98 |
|          | [43] | 0.3424±0.0031 |               | 0.18  |       | 1.00 |
|          | [73] | 0.344±0.013   |               | 0.18  |       | 1.01 |
|          | [73] | 0.336±0.009   |               | -0.60 |       | 0.98 |
|          | [47] | 0.338±0.014   |               | -0.25 |       | 0.99 |
| Z=81, Tl | [58] | 0.366±0.017   | 0.3422±0.0028 | 0.38  | 0.38  | 1.07 |
|          | [49] | 0.339±0.024   |               | -0.13 |       | 0.99 |
|          | [62] | 0.344±0.008   |               | 0.22  |       | 1.01 |
|          | [43] | 0.3396±0.0033 |               | -0.79 |       | 0.99 |
|          | [84] | 0.360±0.032   |               | 0.55  |       | 1.05 |
|          | [85] | 0.358±0.011   |               | 1.39  |       | 1.05 |
|          | [47] | 0.340±0.014   |               | -0.16 |       | 0.99 |
| Z=82, Pb | [58] | 0.363 ±0.017  | 0.3449±0.0025 | 1.06  | -0.23 | 1.05 |
|          | [49] | 0.337±0.029   |               | -0.27 |       | 0.98 |
|          | [65] | 0.343±0.006   |               | -0.29 |       | 0.99 |
|          | [43] | 0.3477±0.0031 |               | 0.71  |       | 1.01 |
|          | [46] | 0.330±0.008   |               | -1.77 |       | 0.96 |
|          | [47] | 0.334±0.013   |               | -0.83 |       | 0.97 |
| Z=83, Bi | [49] | 0.343±0.022   | 0.3468±0.0049 | -0.17 | -0.07 | 0.99 |
|          | [65] | 0.347±0.005   |               | 0.03  |       | 1.00 |
| Z=86, Rn | [49] | 0.343±0.022   | 0.343±0.022   | 0     | 0     | 1.00 |
| Z=88, Ra | [49] | 0.348±0.022   | 0.348±0.022   | 0     | 0     | 1.00 |
| Z=90, Th | [49] | 0.347±0.022   | 0.347±0.022   | 0     | 0     | 1.00 |
| Z=92, U  | [49] | 0.343±0.019   | 0.3617±0.0074 | -0.92 | -0.31 | 0.95 |
|          | [62] | 0.365±0.008   |               | 0.30  |       | 1.01 |
| Z=94, Pu | [62] | 0.369±0.010   | 0.369±0.010   | 0     | 0     | 1.00 |
| Z=96, Cm | [57] | 0.397±0.010   | 0.3832±0.0067 | 1.15  | 0.08  | 1.04 |
|          | [62] | 0.372±0.009   |               | -1.00 |       | 0.97 |

**Table 4.** Summary of the experimental  $K\beta_2/K\alpha_1$  intensity ratios from  $^{30}\text{Zn}$  to  $^{94}\text{Pu}$  according to their target atomic numbers. The references from which the databases are extracted, the combined standard deviation  $z_i$ , the average  $z$ -score  $\bar{z}$ , the ratio  $S$ , and the weighted average values  $(K\beta_2/K\alpha_1)_W$  are also listed.

| Z, Element | References                   | $K\beta_2/K\alpha_1 \pm \Delta (K\alpha_2/K\alpha_1)$     | $(K\beta_2/K\alpha_1)_W \pm \varepsilon$ | $z_i$                         | $\bar{z}$ | $S$                          |
|------------|------------------------------|---|--|-------------------------------|-----------|------------------------------|
| Z=30, Zn   | [51]                         | 0.0106±0.0026   | 0.0106±0.0026                            | 0                             | 0         | 1.00                         |
| Z=31, Ga   | [51]                         | 0.0056±0.0016   | 0.0056±0.0016                            | 0                             | 0         | 1.00                         |
| Z=32, Ge   | [51]                         | 0.0051±0.0014   | 0.0051±0.0014                            | 0                             | 0         | 1.00                         |
| Z=33, As   | [51]                         | 0.0143±0.00093  | 0.0143±0.00093                           | 0                             | 0         | 1.00                         |
| Z=34, Se   | [51]                         | 0.0105±0.0035   | 0.0105±0.0035                            | 0                             | 0         | 1.00                         |
| Z=35, Br   | [51]                         | 0.0128±0.00085  | 0.0128±0.00085                           | 0                             | 0         | 1.00                         |
| Z=37, Rb   | [41]<br>[51]                 | 0.025±0.0010<br>0.0185±0.00070                            | 0.0206±0.0006                            | 3.78<br>-2.36                 | 0.71      | 1.21<br>0.90                 |
| Z=38, Sr   | [51]                         | 0.0233±0.0025   | 0.0233±0.0025                            | 0                             | 0         | 1.00                         |
| Z=39, Y    | [51]                         | 0.0247±0.0018   | 0.0247±0.0018                            | 0                             | 0         | 1.00                         |
| Z=40, Zr   | [41]                         | 0.037±0.0020  | 0.037±0.0020                             | 0                             | 0         | 1.00                         |
| Z=41, Nb   | [51]                         | 0.0235±0.0019   | 0.0235±0.0019                            | 0                             | 0         | 1.00                         |
| Z=42, Mo   | [41]<br>[51]                 | 0.043±0.0020<br>0.0289±0.0023                             | 0.0369±0.0015                            | 2.42<br>-2.92                 | -0.25     | 1.16<br>0.78                 |
| Z=45, Rh   | [41]<br>[51]                 | 0.046±0.0020<br>0.0317±0.0017                             | 0.0377±0.0013                            | 3.48<br>-2.81                 | 0.34      | 1.22<br>0.84                 |
| Z=46, Pd   | [51]                         | 0.0317±0.0011   | 0.0317±0.0011                            | 0                             | 0         | 1.00                         |
| Z=47, Ag   | [41]<br>[51]                 | 0.049±0.0030<br>0.0314±0.00069                            | 0.0323±0.0007                            | 5.44<br>-0.92                 | 2.26      | 1.52<br>0.97                 |
| Z=48, Cd   | [51]                         | 0.0466±0.00055  | 0.0466±0.00055                           | 0                             | 0         | 1.00                         |
| Z=49, In   | [51]                         | 0.0500±0.00076  | 0.0500±0.00076                           | 0                             | 0         | 1.00                         |
| Z=50, Sn   | [41]<br>[51]                 | 0.055±0.0030<br>0.0537±0.00059                            | 0.0537±0.0006                            | 0.41<br>-0.06                 | 0.18      | 1.02<br>1.00                 |
| Z=51, Sb   | [51]                         | 0.0560±0.00094  | 0.0560±0.00094                           | 0                             | 0         | 1.00                         |
| Z=52, Te   | [51]                         | 0.0588±0.0018   | 0.0588±0.0018                            | 0                             | 0         | 1.00                         |
| Z=53, I    | [41]<br>[51]                 | 0.060±0.0030<br>0.0613±0.0020                             | 0.0609±0.0017                            | -0.26<br>0.15                 | -0.05     | 0.99<br>1.01                 |
| Z=55, Cs   | [51]                         | 0.0660±0.0027   | 0.0660±0.0027                            | 0                             | 0         | 1.00                         |
| Z=56, Ba   | [41]<br>[51]                 | 0.071±0.0040<br>0.0697±0.0027                             | 0.0701±0.0022                            | 0.19<br>-0.12                 | 0.04      | 1.01<br>0.99                 |
| Z=57, La   | [51]                         | 0.0712±0.0021   | 0.0712±0.0021                            | 0                             | 0         | 1.00                         |
| Z=58, Ce   | [41]<br>[51]                 | 0.080±0.0040<br>0.0629±0.0073                             | 0.0716±0.0035                            | 0.74<br>-1.62                 | -0.44     | 1.05<br>0.83                 |
| Z=60, Nd   | [52]                         | 0.071±0.0066  | 0.071±0.0066                             | 0                             | 0         | 1.00                         |
| Z=62, Sm   | [41]<br>[52]                 | 0.075±0.0040<br>0.081±0.0075                              | 0.0763±0.0035                            | -0.25<br>0.56                 | 0.16      | 0.98<br>1.06                 |
| Z=63, Eu   | [52]                         | 0.091±0.0083  | 0.091±0.0083                             | 0                             | 0         | 1.00                         |
| Z=64, Gd   | [41]<br>[52]                 | 0.087±0.0040<br>0.075±0.0069                              | 0.0840±0.0035                            | 0.57<br>-1.16                 | -0.30     | 1.04<br>0.89                 |
| Z=65, Tb   | [53]                         | 0.091±0.0083  | 0.091±0.0083                             | 0                             | 0         | 1.00                         |
| Z=66, Dy   | [52]<br>[53]                 | 0.089±0.0082<br>0.070±0.003                               | 0.0722±0.0028                            | 1.93<br>-0.54                 | 0.69      | 1.23<br>0.97                 |
| Z=67, Ho   | [41]<br>[53]                 | 0.088±0.0050<br>0.073±0.003                               | 0.0770±0.0026                            | 1.96<br>-1.00                 | 0.48      | 1.14<br>0.95                 |
| Z=68, Er   | [52]<br>[53]                 | 0.10±0.0092<br>0.080±0.004                                | 0.0832±0.0037                            | 1.70<br>-0.59                 | 0.56      | 1.20<br>0.96                 |
| Z=69, Tm   | [53]                         | 0.071±0.004   | 0.071±0.004                              | 0                             | 0         | 1.00                         |
| Z=70, Yb   | [41]<br>[70]<br>[52]<br>[53] | 0.089±0.0050<br>0.078±0.0024<br>0.11±0.010<br>0.084±0.004 | 0.0820±0.0019                            | 1.32<br>-1.30<br>2.76<br>0.46 | 0.81      | 1.09<br>0.95<br>1.34<br>1.02 |
| Z=71, Lu   | [53]                         | 0.088±0.004   | 0.088±0.004                              | 0                             | 0         | 1.00                         |
| Z=72, Hf   | [70]<br>[53]                 | 0.089±0.0020<br>0.088±0.004                               | 0.0888±0.0018                            | 0.07<br>-0.18                 | -0.05     | 1.00<br>0.99                 |
| Z=73, Ta   | [41]<br>[53]                 | 0.090±0.005 0<br>0.076±0.003                              | 0.0797±0.0026                            | 1.38<br>-0.94                 | 0.45      | 1.13<br>0.95                 |
| Z=74, W    | [50]                         | 0.088±0.0055  | 0.0841±0.0032                            | 0.62                          | 0.11      | 1.05                         |

|          |      |               |               |       |       |      |
|----------|------|---------------|---------------|-------|-------|------|
|          | [53] | 0.082±0.004   |               | -0.40 |       | 0.98 |
| Z=75, Re | [53] | 0.088±0.004   | 0.088±0.004   | 0     | 0     | 1.00 |
| Z=76, Os | [68] | 0.0825±0.0023 | 0.0814±0.0020 | 0.37  | -0.19 | 1.01 |
|          | [53] | 0.078±0.004   |               | -0.76 |       | 0.96 |
| Z=77, Ir | [41] | 0.096±0.0050  | 0.0856±0.0031 | 1.76  | 0.23  | 1.12 |
|          | [53] | 0.079±0.004   |               | -1.31 |       | 0.92 |
| Z=78, Pt | [68] | 0.0922±0.0020 | 0.0910±0.0018 | 0.45  | 0.12  | 1.01 |
|          | [53] | 0.084±0.004   |               | -1.60 |       | 0.92 |
|          | [46] | 0.108±0.011   |               | 1.53  |       | 1.19 |
| Z=79, Au | [41] | 0.098±0.0050  | 0.0942±0.0027 | 0.66  | 0.02  | 1.04 |
|          | [50] | 0.097±0.0061  |               | 0.41  |       | 1.03 |
|          | [53] | 0.091±0.004   |               | -0.67 |       | 0.97 |
|          | [46] | 0.089±0.015   |               | -0.34 |       | 0.94 |
| Z=80, Hg | [53] | 0.096±0.005   | 0.096±0.005   | 0     | 0     | 1.00 |
| Z=81, Tl | [50] | 0.099±0.0062  | 0.0891±0.0034 | 1.40  | 0.31  | 1.11 |
|          | [53] | 0.085±0.004   |               | -0.79 |       | 0.95 |
| Z=82, Pb | [41] | 0.098±0.0050  | 0.0841±0.0009 | 2.72  | 1.03  | 1.16 |
|          | [42] | 0.083±0.001   |               | -0.83 |       | 0.99 |
|          | [50] | 0.100±0.0063  |               | 2.49  |       | 1.19 |
|          | [53] | 0.087±0.004   |               | 0.70  |       | 1.03 |
|          | [46] | 0.085±0.01    |               | 0.09  |       | 1.01 |
| Z=83, Bi | [41] | 0.101±0.0050  | 0.0953±0.0028 | 1.00  | 0.22  | 1.06 |
|          | [50] | 0.102±0.0064  |               | 0.96  |       | 1.07 |
|          | [53] | 0.089±0.004   |               | -1.29 |       | 0.93 |
| Z=90, Th | [41] | 0.115±0.0060  | 0.1029±0.0032 | 1.78  | 0.18  | 1.12 |
|          | [50] | 0.109±0.0059  |               | 0.91  |       | 1.06 |
|          | [53] | 0.090±0.005   |               | -2.16 |       | 0.88 |
| Z=92, U  | [41] | 0.113±0.0060  | 0.1034±0.0032 | 1.41  | 0.16  | 1.09 |
|          | [50] | 0.110±0.0059  |               | 0.98  |       | 1.06 |
|          | [53] | 0.092±0.005   |               | -1.92 |       | 0.89 |
|          | [42] | 0.0925 ±0.001 |               |       |       | 0.89 |
| Z=94, Pu | [41] | 0.120±0.0060  | 0.120±0.0060  | 0     | 0     | 1.00 |

**Table 5.** Summary of the experimental  $K\beta'_2/K\alpha_1$  intensity ratios from  $_{40}\text{Zr}$  to  $_{96}\text{Cm}$  according to their target atomic numbers. The references from which the databases are extracted, the combined standard deviation  $z_i$ , the average  $z$ -score  $\bar{z}$ , the ratio  $S$ , and the weighted average values  $(K\beta'_2/K\alpha_1)_W$  are also listed.

| Z, Element | References                           | $K\beta'_2/K\alpha_1 \pm \Delta (K\beta'_2/K\alpha_1)$                          | $(K\beta'_2/K\alpha_1)_W \pm \varepsilon$ | $z_i$                                    | $\bar{z}$ | $S$                                  |
|------------|--------------------------------------|---|---|--|-----------|--------------------------------------|
| Z=40, Zr   | [90]                                 | 0.0361 ± 0.0015   | 0.0361 ± 0.0015                           | 0  | 0         | 1.00                                 |
| Z=41, Nb   | [90]                                 | 0.0384 ± 0.0015   | 0.0384 ± 0.0015                           | 0  | 0         | 1.00                                 |
| Z=42, Mo   | [90]                                 | 0.0420 ± 0.0015   | 0.0420 ± 0.0015                           | 0  | 0         | 1.00                                 |
| Z=44, Ru   | [90]                                 | 0.0448 ± 0.0012   | 0.0448 ± 0.0012                           | 0  | 0         | 1.00                                 |
| Z=45, Rh   | [90]                                 | 0.0464 ± 0.0010   | 0.0464 ± 0.0010                           | 0  | 0         | 1.00                                 |
| Z=46, Pd   | [90]                                 | 0.0470 ± 0.0008   | 0.0470 ± 0.0008                           | 0  | 0         | 1.00                                 |
| Z=47, Ag   | [90]                                 | 0.0501 ± 0.0010   | 0.0501 ± 0.0010                           | 0  | 0         | 1.00                                 |
| Z=48, Cd   | [90]                                 | 0.0515 ± 0.0012   | 0.0515 ± 0.0012                           | 0  | 0         | 1.00                                 |
| Z=49, In   | [90]                                 | 0.0541±0.0012   | 0.0541±0.0012                             | 0  | 0         | 1.00                                 |
| Z=50, Sn   | [90]                                 | 0.0562 ± 0.0014   | 0.0562 ± 0.0014                           | 0  | 0         | 1.00                                 |
| Z=56, Ba   | [82]                                 | 0.0598±0.0030   | 0.0598±0.0030                             | 0  | 0         | 1.00                                 |
| Z=57, La   | [87]                                 | 0.074±0.003   | 0.074±0.003                               | 0  | 0         | 1.00                                 |
| Z=58, Ce   | [87]                                 | 0.066±0.002   | 0.066±0.002                               | 0  | 0         | 1.00                                 |
| Z=59, Pr   | [87]                                 | 0.075±0.002   | 0.075±0.002                               | 0  | 0         | 1.00                                 |
| Z=60, Nd   | [82]<br>[87]                         | 0.0718±0.0036<br>0.073±0.003  | 0.0725±0.0023                             | -0.17<br>0.13                            | -0.02     | 0.99<br>1.01                         |
| Z=62, Sm   | [82]<br>[87]                         | 0.0722±0.0036<br>0.066±0.002  | 0.0675±0.0017                             | 1.08<br>-0.55                            | 0.32      | 1.07<br>0.98                         |
| Z=63, Eu   | [82]<br>[87]                         | 0.0713±0.0036<br>0.066±0.002  | 0.0672±0.0017                             | 1.01<br>-0.47                            | 0.27      | 1.06<br>0.98                         |
| Z=64, Gd   | [82]<br>[87]                         | 0.0713±0.0036<br>0.075±0.003  | 0.0735±0.0023                             | -0.51<br>0.40                            | -0.06     | 0.97<br>1.02                         |
| Z=65, Tb   | [87]                                 | 0.075±0.003   | 0.075±0.003                               | 0  | 0         | 1.00                                 |
| Z=66, Dy   | [82]<br>[87]                         | 0.0757±0.0038<br>0.080±0.004  | 0.0777±0.0028                             | -0.43<br>0.47                            | 0.02      | 0.97<br>1.03                         |
| Z=67, Ho   | [65]<br>[82]                         | 0.082±0.001<br>0.0766±0.0038  | 0.0817±0.0010                             | 0.25<br>-1.29                            | -0.52     | 1.00<br>0.94                         |
| Z=68, Er   | [72]<br>[73]<br>[87]                 | 0.0764±0.0020<br>0.0776±0.0043<br>0.086±0.004                                   | 0.0782±0.017                              | -0.70<br>-0.13<br>1.80                   | 0.32      | 0.98<br>0.99<br>1.10                 |
| Z=69, Tm   | [65]<br>[91]                         | 0.083±0.002<br>0.0802±0.0012  | 0.0809±0.0010                             | 0.92<br>-0.47                            | 0.22      | 1.03<br>0.99                         |
| Z=70, Yb   | [91]                                 | 0.0837±0.0013   | 0.0837±0.0013                             | 0  | 0         | 1.00                                 |
| Z=71, Lu   | [91]<br>[47]                         | 0.0861±0.0022<br>0.076 ±0.003   | 0.0826±0.0018                             | 1.25<br>-1.88                            | -0.32     | 1.04<br>0.92                         |
| Z=73, Ta   | [91]                                 | 0.0862±0.0022   | 0.0862±0.0022                             | 0  | 0         | 1.00                                 |
| Z=74, W    | [91]<br>[38]<br>[47]                 | 0.0910±0.0018<br>0.0806±0.0048<br>0.091±0.004                                   | 0.0899±0.0016                             | 0.46<br>-1.85<br>0.25                    | -0.38     | 1.01<br>0.90<br>1.01                 |
| Z=75, Re   | [91]<br>[38]                         | 0.0976±0.0023<br>0.0927±0.0056  | 0.0969±0.0021                             | 0.23<br>-0.70                            | -0.24     | 1.01<br>0.96                         |
| Z=76, Os   | [38]                                 | 0.0861±0.0052   | 0.0861±0.0052                             | 0  | 0         | 1.00                                 |
| Z=78, Pt   | [38]                                 | 0.0886±0.0053   | 0.0886±0.0053                             | 0  | 0         | 1.00                                 |
| Z=79, Au   | [65]<br>[43]<br>[91]<br>[83]         | 0.090±0.014<br>0.0977±0.0011<br>0.0976±0.0023<br>0.0895±0.0045                  | 0.0973±0.0010                             | -0.52<br>0.30<br>0.13<br>-1.69           | -0.44     | 0.93<br>1.00<br>1.00<br>0.92         |
| Z=80, Hg   | [43]<br>[73]<br>[73]<br>[91]<br>[47] | 0.1015±0.0011<br>0.0972±0.0057<br>0.0969±0.0026<br>0.0981±0.0023<br>0.096±0.004 | 0.1001±0.0009                             | 1.01<br>-0.50<br>-1.15<br>-0.80<br>-0.99 | -0.49     | 1.01<br>0.97<br>0.97<br>0.98<br>0.96 |
| Z=81, Tl   | [58]<br>[62]<br>[43]<br>[91]<br>[47] | 0.101±0.005<br>0.102±0.004<br>0.1029±0.0011<br>0.1011±0.0034<br>0.099±0.004     | 0.1024±0.0010                             | -0.28<br>-0.10<br>0.34<br>-0.37<br>-0.38 | -0.25     | 0.99<br>1.00<br>1.00<br>0.99<br>0.97 |

|          |                                      |  |               |  |       |                                      |
|----------|--------------------------------------|--|---------------|--|-------|--------------------------------------|
| Z=82, Pb | [58]<br>[65]<br>[43]<br>[91]<br>[47] | 0.103 ±0.005<br>0.105±0.004<br>0.1050±0.0012<br>0.1086±0.0035<br>0.094±0.004 | 0.1045±0.0010 | -0.29<br>0.12<br>0.32<br>1.12<br>-0.54 | -0.25 | 0.99<br>1.00<br>1.00<br>1.04<br>0.90 |
| Z=83, Bi | [65]<br>[91]                         | 0.108±0.001<br>0.1086±0.0035   | 0.1080±0.0010 | -0.03<br>0.15                          | 0.06  | 1.00<br>1.01                         |
| Z=86, Rn | [49]                                 | 0.084±0.007  | 0.084±0.007   | 0                                      | 0     | 1.00                                 |
| Z=88, Ra | [49]                                 | 0.086±0.007  | 0.086±0.007   | 0                                      | 0     | 1.00                                 |
| Z=90, Th | [49]<br>[91]                         | 0.086±0.007<br>0.1142±0.0047   | 0.1054±0.0039 | -2.43<br>1.43                          | -0.50 | 0.82<br>1.08                         |
| Z=92, U  | [49]<br>[62]<br>[91]                 | 0.090±0.006<br>0.125±0.004<br>0.1258±0.0059                                  | 0.1170±0.0029 | -4.06<br>1.61<br>1.34                  | -0.37 | 0.77<br>1.07<br>1.07                 |
| Z=94, Pu | [62]                                 | 0.127±0.004  | 0.127±0.004   | 0                                      | 0     | 1.00                                 |
| Z=96, Cm | [57]<br>[62]                         | 0.133±0.005<br>0.133±0.005   | 0.1330±0.0035 | 0<br>0                                 | 0     | 1.00<br>1.00                         |

**Table 6.** Summary of the experimental  $K\beta'_2/K\beta'_1$  intensity ratios from  ${}_{40}\text{Zr}$  to  ${}_{92}\text{U}$  according to their target atomic numbers. The references from which the databases are extracted, the combined standard deviation  $z_i$ , the average  $z$ -score  $\bar{z}$ , the ratio  $S$ , and the weighted average values  $(K\beta'_2/K\beta'_1)_W$  are also listed.

| Z, Element | References | $K\beta'_2/K\beta'_1 \pm \Delta (K\beta'_2/K\beta'_1)$ | $(K\beta'_2/K\beta'_1)_W \pm \varepsilon$ | $z_i$ | $\bar{z}$ | $S$  |
|------------|------------|--|---|-------|-----------|------|
| Z=40, Zr   | [90]       | 0.1430 ± 0.006   | 0.1430 ± 0.006                            | 0     | 0         | 1.00 |
| Z=41, Nb   | [90]       | 0.1490 ± 0.0054  | 0.1490 ± 0.0054                           | 0     | 0         | 1.00 |
| Z=42, Mo   | [93]       | 0.1538 ± 0.0008  | 0.1540±0.0008                             | -0.19 | 0.73      | 1.00 |
|            | [90]       | 0.1624 ± 0.005   |   | 1.066 |           | 1.05 |
| Z=44, Ru   | [93]       | 0.1596 ± 0.0008  | 0.1600±0.0008                             | -0.32 | 0.96      | 1.00 |
|            | [90]       | 0.1693 ± 0.0041  |   | 2.24  |           | 1.06 |
| Z=45, Rh   | [93]       | 0.1648 ± 0.0006  | 0.1650±0.0006                             | -0.19 | 0.70      | 1.00 |
|            | [90]       | 0.1708 ± 0.0036  |   | 1.60  |           | 1.04 |
| Z=46, Pd   | [93]       | 0.1671 ± 0.0008  | 0.1675±0.0008                             | -0.41 | 0.82      | 1.00 |
|            | [90]       | 0.1739 ± 0.003   |   | 2.05  |           | 1.04 |
| Z=47, Ag   | [74]       | 0.1840±0.0018  | 0.1764±0.0006                             | 4.02  | 1.77      | 1.04 |
|            | [92]       | 0.1752±0.0006  |   | -1.49 |           | 0.99 |
|            | [90]       | 0.1841 ± 0.0027  |   | 2.79  |           | 1.04 |
| Z=48, Cd   | [92]       | 0.1796±0.0006  | 0.1800±0.0006                             | -0.46 | 1.24      | 1.00 |
|            | [90]       | 0.1884 ± 0.0028  |   | 2.94  |           | 1.05 |
| Z=49, In   | [74]       | 0.1951±0.0018  | 0.1944±0.0010                             | 0.34  | 0.07      | 1.00 |
|            | [90]       | 0.1941 ± 0.0012  |   | -0.20 |           | 1.00 |
| Z=50, Sn   | [92]       | 0.191±0.001  | 0.1939±0.0008                             | -2.30 | 0.48      | 0.98 |
|            | [90]       | 0.1989 ± 0.0013  |   | 3.26  |           | 1.03 |
| Z=52, Te   | [74]       | 0.2153±0.0021  | 0.2153±0.0021                             | 0     | 0         | 1.00 |
| Z=54, Xe   | [73]       | 0.230±0.010  | 0.230±0.010                               | 0     | 0         | 1.00 |
| Z=55, Cs   | [72]       | 0.229±0.0089   | 0.2510±0.0022                             | -2.40 | -0.97     | 0.91 |
|            | [74]       | 0.2525±0.0023  |   | 0.46  |           | 1.01 |
| Z=56, Ba   | [71]       | 0.245±0.0065   | 0.2518±0.0023                             | -0.98 | -0.52     | 0.97 |
|            | [72]       | 0.225±0.029  |   | -0.92 |           | 0.89 |
|            | [74]       | 0.2530±0.0025  |   | 0.35  |           | 1.00 |
| Z=59, Pr   | [70]       | 0.244±0.0061   | 0.244±0.0061                              | 0     | 0         | 1.00 |
| Z=62, Sm   | [45]       | 0.24±0.018   | 0.24±0.018                                | 0     | 0         | 1.00 |
| Z=63, Eu   | [45]       | 0.26±0.019   | 0.26±0.019                                | 0     | 0         | 1.00 |
| Z=64, Gd   | [45]       | 0.31±0.023   | 0.31±0.023                                | 0     | 0         | 1.00 |
| Z=66, Dy   | [45]       | 0.31±0.023   | 0.31±0.023                                | 0     | 0         | 1.00 |
| Z=67, Ho   | [65]       | 0.26±0.007   | 0.2655±0.0067                             | -0.57 | 1.01      | 0.98 |
|            | [45]       | 0.33±0.024   |   | 2.59  |           | 1.24 |
| Z=68, Er   | [72]       | 0.247±0.0063   | 0.2462±0.0057                             | 0.10  | -0.09     | 1.00 |
|            | [73]       | 0.242±0.014  |   | -0.27 |           | 0.98 |
| Z=69, Tm   | [65]       | 0.27±0.01  | 0.2635±0.0083                             | 0.50  | -0.18     | 1.02 |
|            | [91]       | 0.249±0.015  |   | -0.85 |           | 0.94 |
| Z=71, Lu   | [91]       | 0.264±0.013  | 0.264±0.013                               | 0     | 0         | 1.00 |
| Z=73, Ta   | [59]       | 0.239±0.012  | 0.2505±0.0088                             | -0.77 | 0.04      | 0.95 |
|            | [91]       | 0.264±0.013  |   | 0.86  |           | 1.05 |
| Z=74, W    | [91]       | 0.265±0.016  | 0.265±0.016                               | 0     | 0         | 1.00 |
| Z=75, Re   | [91]       | 0.276±0.017  | 0.276±0.017                               | 0     | 0         | 1.00 |
| Z=79, Au   | [59]       | 0.268±0.013  | 0.2765±0.0097                             | -0.53 | 0.07      | 0.97 |
|            | [65]       | 0.27±0.055   |   | -0.12 |           | 0.98 |
|            | [43]       | 0.287±0.033  |   | 0.30  |           | 1.04 |
|            | [91]       | 0.289±0.017  |   | 0.64  |           | 1.05 |
| Z=80, Hg   | [73]       | 0.282±0.016  | 0.2935±0.0035                             | -0.70 | -0.28     | 0.96 |
|            | [73]       | 0.288±0.0071   |   | -0.70 |           | 0.98 |
|            | [43]       | 0.2964±0.0042  |   | 0.53  |           | 1.01 |
|            | [91]       | 0.291±0.018  |   | -0.14 |           | 0.99 |
| Z=81, Tl   | [71]       | 0.286±0.0087   | 0.2991±0.0038                             | -1.40 | -0.34     | 0.96 |
|            | [43]       | 0.3030±0.0044  |   | 0.63  |           | 1.01 |
|            | [91]       | 0.295±0.018  |   | -0.24 |           | 0.99 |
| Z=82, Pb   | [65]       | 0.306±0.017  | 0.3028±0.0042                             | 0.19  | 0.21      | 1.01 |
|            | [43]       | 0.3020±0.0044  |   | -0.12 |           | 1.00 |
|            | [91]       | 0.315±0.021  |   | 0.57  |           | 1.04 |
| Z=83, Bi   | [59]       | 0.297±0.015  | 0.3094±0.0062                             | -0.76 | -0.01     | 0.96 |

|          |              |                            |               |               |      |              |
|----------|--------------|----------------------------|---------------|---------------|------|--------------|
|          | [65]<br>[91] | 0.311±0.007<br>0.324±0.026 |               | 0.18<br>0.55  |      | 1.01<br>1.05 |
| Z=86, Rn | [49]         | 0.245±0.026                | 0.245±0.026   | 0             | 0    | 1.00         |
| Z=88, Ra | [49]         | 0.247±0.025                | 0.247±0.025   | 0             | 0    | 1.00         |
| Z=90, Th | [49]<br>[91] | 0.248±0.025<br>0.327±0.028 | 0.2830±0.0186 | -1.12<br>1.31 | 0.09 | 0.88<br>1.16 |
| Z=92, U  | [49]<br>[91] | 0.263±0.023<br>0.347±0.032 | 0.2916±0.0187 | -0.97<br>1.49 | 0.26 | 0.90<br>1.19 |

**Table 7.** Summary of the experimental  $K\beta_3/K\beta_1$  intensity ratios from  ${}_{39}\text{Y}$  to  ${}_{99}\text{Es}$  according to their target atomic numbers. The references from which the databases are extracted, the combined standard deviation  $z_i$ , the average  $z$ -score  $\bar{z}$ , the ratio  $S$ , and the weighted average values  $(K\beta_3/K\beta_1)_W$  are also listed.

| Z, Element | References                   | $K\beta_3/K\beta_1 \pm \Delta(K\beta_3/K\beta_1)$         | $(K\beta_3/K\beta_1)_W \pm \varepsilon$ | $z_i$                           | $\bar{z}$ | $S$                          |
|------------|------------------------------|---|---|---------------------------------|-----------|------------------------------|
| Z=39, Y    | [89]                         | 0.526±0.018   | 0.526±0.018                             | 0                               | 0         | 1.00                         |
| Z=40, Zr   | [89]                         | 0.5049±0.0060   | 0.5049±0.0060                           | 0                               | 0         | 1.00                         |
| Z=42, Mo   | [95]                         | 0.512±0.012   | 0.512±0.012                             | 0                               | 0         | 1.00                         |
| Z=46, Pd   | [95]                         | 0.511±0.010   | 0.511±0.010                             | 0                               | 0         | 1.00                         |
| Z=47, Ag   | [95]                         | 0.511±0.012   | 0.511±0.012                             | 0                               | 0         | 1.00                         |
| Z=48, Cd   | [95]                         | 0.513±0.027   | 0.513±0.027                             | 0                               | 0         | 1.00                         |
| Z=49, In   | [94]<br>[95]                 | 0.514±0.010<br>0.504±0.023                                | 0.5124±0.0092                           | 0.12<br>-0.34                   | -0.11     | 1.00<br>0.98                 |
| Z=50, Sn   | [94]<br>[95]                 | 0.514±0.010<br>0.512±0.014                                | 0.5133±0.0081                           | 0.05<br>-0.08                   | -0.01     | 1.00<br>1.00                 |
| Z=51, Sb   | [95]                         | 0.513±0.022   | 0.513±0.022                             | 0                               | 0         | 1.00                         |
| Z=52, Te   | [94]<br>[95]                 | 0.515±0.010<br>0.515±0.044                                | 0.515±0.0098                            | 0<br>0                          | 0         | 1.00<br>1.00                 |
| Z=58, Ce   | [94]                         | 0.519±0.010   | 0.519±0.010                             | 0                               | 0         | 1.00                         |
| Z=65, Tb   | [94]                         | 0.522±0.010   | 0.522±0.010                             | 0                               | 0         | 1.00                         |
| Z=70, Yb   | [96]                         | 0.5152±0.0035   | 0.5152±0.0035                           | 0                               | 0         | 1.00                         |
| Z=73, Ta   | [94]                         | 0.527±0.011   | 0.527±0.011                             | 0                               | 0         | 1.00                         |
| Z=75, Re   | [94]                         | 0.529±0.011   | 0.529±0.011                             | 0                               | 0         | 1.00                         |
| Z=78, Pt   | [96]                         | 0.5119±0.0014   | 0.5119±0.0014                           | 0                               | 0         | 1.00                         |
| Z=79, Au   | [94]                         | 0.531±0.011   | 0.531±0.011                             | 0                               | 0         | 1.00                         |
| Z=80, Hg   | [49]                         | 0.500±0.064   | 0.500±0.064                             | 0                               | 0         | 1.00                         |
| Z=81, Tl   | [49]                         | 0.514±0.050   | 0.514±0.050                             | 0                               | 0         | 1.00                         |
| Z=82, Pb   | [94]<br>[49]<br>[96]         | 0.534±0.016<br>0.500±0.061<br>0.5124±0.0011               | 0.5125±0.0011                           | 1.34<br>-0.20<br>-0.06          | 0.36      | 1.04<br>0.98<br>1.00         |
| Z=83, Bi   | [49]                         | 0.527±0.046   | 0.527±0.046                             | 0                               | 0         | 1.00                         |
| Z=86, Rn   | [49]                         | 0.527±0.046   | 0.527±0.046                             | 0                               | 0         | 1.00                         |
| Z=88, Ra   | [49]                         | 0.516±0.045   | 0.516±0.045                             | 0                               | 0         | 1.00                         |
| Z=90, Th   | [94]<br>[49]<br>[66]         | 0.540±0.016<br>0.507±0.044<br>0.53±0.060                  | 0.5358±0.0146                           | 0.19<br>-0.62<br>-0.09          | -0.17     | 1.01<br>0.95<br>0.99         |
| Z=91, Pa   | [66]                         | 0.55±0.052  | 0.55±0.052                              | 0                               | 0         | 1.00                         |
| Z=92, U    | [94]<br>[49]<br>[66]<br>[96] | 0.543±0.016<br>0.523±0.039<br>0.46±0.046<br>0.5080±0.0007 | 0.5081±0.0007                           | 2.018<br>0.38<br>-1.04<br>-0.06 | 0.36      | 1.07<br>1.03<br>0.91<br>1.00 |
| Z=93, Np   | [94]<br>[66]                 | 0.544±0.016<br>0.48±0.048                                 | 0.5376±0.0152                           | 0.29<br>-1.14                   | -0.43     | 1.01<br>0.89                 |
| Z=94, Pu   | [94]<br>[66]                 | 0.545±0.016<br>0.50±0.051                                 | 0.5410±0.0153                           | 0.18<br>-0.77                   | -0.29     | 1.01<br>0.92                 |
| Z=95, Am   | [94]<br>[66]                 | 0.546±0.016<br>0.45±0.050                                 | 0.5371±0.0152                           | 0.40<br>-1.67                   | -0.63     | 1.02<br>0.84                 |
| Z=96, Cm   | [61]<br>[66]                 | 0.487±0.017<br>0.52±0.054                                 | 0.4900±0.0162                           | -0.13<br>0.53                   | 0.20      | 0.99<br>1.06                 |
| Z=97, Bk   | [61]<br>[66]                 | 0.568±0.031<br>0.61±0.051                                 | 0.5793±0.0265                           | -0.28<br>0.53                   | 0.13      | 0.98<br>1.05                 |
| Z=98, Cf   | [61]                         | 0.514±0.025   | 0.514±0.025                             | 0                               | 0         | 1.00                         |
| Z=99, Es   | [61]                         | 0.554±0.037   | 0.554±0.037                             | 0                               | 0         | 1.00                         |

**Table 8.** The coefficients derived from the polynomial fits applied in the semi-empirical determination of the  $R$  intensity ratios (see Eqs. (3) and (4)).

| R                     | Z-range               | Function | Ordre<br>$m,n$ | $a_i, b_i$ | Value                     |
|-----------------------|-----------------------|----------|----------------|------------|---------------------------|
| $K\alpha_2/K\alpha_1$ | $(13 \leq Z \leq 99)$ | g(Z)     | 3              | $a_0$      | 1.00571                   |
|                       |                       |          |                | $a_1$      | $5.33598 \times 10^{-5}$  |
|                       |                       |          |                | $a_2$      | $2.91396 \times 10^{-6}$  |
|                       |                       |          |                | $a_3$      | $1.2669 \times 10^{-7}$   |
|                       |                       | f(Z)     | 3              | $b_0$      | 1.01227                   |
|                       |                       |          |                | $b_1$      | $-7.93239 \times 10^{-4}$ |
|                       |                       |          |                | $b_2$      | $1.95575 \times 10^{-5}$  |
|                       |                       |          |                | $b_3$      | $-1.35903 \times 10^{-7}$ |
| $K\beta'_1/K\alpha_1$ | $(24 \leq Z \leq 96)$ | g(Z)     | 3              | $a_0$      | 0.41485                   |
|                       |                       |          |                | $a_1$      | 0.01411                   |
|                       |                       |          |                | $a_2$      | $-1.71283 \times 10^{-4}$ |
|                       |                       |          |                | $a_3$      | $7.77842 \times 10^{-7}$  |
|                       |                       | f(Z)     | 3              | $b_0$      | 1.03947                   |
|                       |                       |          |                | $b_1$      | -0.00375                  |
|                       |                       |          |                | $b_2$      | $9.34039 \times 10^{-5}$  |
|                       |                       |          |                | $b_3$      | $-6.38185 \times 10^{-7}$ |
| $K\beta_2/K\alpha_1$  | $(30 \leq Z \leq 94)$ | g(Z)     | 3              | $a_0$      | -0.54834                  |
|                       |                       |          |                | $a_1$      | 0.04133                   |
|                       |                       |          |                | $a_2$      | $-5.30368 \times 10^{-4}$ |
|                       |                       |          |                | $a_3$      | $2.34121 \times 10^{-6}$  |
|                       |                       | f(Z)     | 3              | $b_0$      | 1.13605                   |
|                       |                       |          |                | $b_1$      | -0.00808                  |
|                       |                       |          |                | $b_2$      | $1.65335 \times 10^{-4}$  |
|                       |                       |          |                | $b_3$      | $-1.00938 \times 10^{-6}$ |
|                       |                       |          | 3              | $a_0$      | -0.11594                  |

|                       |                           |        |   |       |                           |                           |
|-----------------------|---------------------------|--------|---|-------|---------------------------|---------------------------|
| $K\beta'_2/K\alpha_1$ | $(40 \leq Z \leq 96)$     | $g(Z)$ |   | $a_1$ | 0.0237                    |                           |
|                       |                           |        |   | $a_2$ | $-2.99401 \times 10^{-4}$ |                           |
|                       |                           |        |   | $a_3$ | $1.37395 \times 10^{-6}$  |                           |
|                       |                           | $f(Z)$ |   | 3     | $b_0$                     | 0.56257                   |
|                       |                           |        |   |       | $b_1$                     | 0.02099                   |
|                       |                           |        |   |       | $b_2$                     | $-3.17133 \times 10^{-4}$ |
|                       |                           |        |   |       | $b_3$                     | $1.50593 \times 10^{-6}$  |
| $K\beta'_2/K\beta'_1$ | $(40 \leq Z \leq 92)$     | $g(Z)$ | 3 | $a_0$ | -0.21928                  |                           |
|                       |                           |        |   | $a_1$ | 0.03413                   |                           |
|                       |                           |        |   | $a_2$ | $-3.79213 \times 10^{-4}$ |                           |
|                       |                           |        |   | $a_3$ | $1.3801 \times 10^{-6}$   |                           |
|                       |                           | $f(Z)$ |   | 3     | $b_0$                     | 1.18594                   |
|                       |                           |        |   |       | $b_1$                     | -0.00606                  |
|                       |                           |        |   |       | $b_2$                     | $5.1752 \times 10^{-5}$   |
| $b_3$                 | $-5.41933 \times 10^{-8}$ |        |   |       |                           |                           |
| $K\beta_3/K\beta_1$   | $(39 \leq Z \leq 99)$     | $g(Z)$ | 3 | $a_0$ | 0.94016                   |                           |
|                       |                           |        |   | $a_1$ | 0.00378                   |                           |
|                       |                           |        |   | $a_2$ | $-6.38359 \times 10^{-5}$ |                           |
|                       |                           |        |   | $a_3$ | $3.63665 \times 10^{-7}$  |                           |
|                       |                           | $f(Z)$ |   | 3     | $b_0$                     | 0.93806                   |
|                       |                           |        |   |       | $b_1$                     | 0.00243                   |
|                       |                           |        |   |       | $b_2$                     | $-2.77414 \times 10^{-5}$ |
| $b_3$                 | $8.19274 \times 10^{-8}$  |        |   |       |                           |                           |

**Table 9.** Theoretical and semi-empirical  $K\alpha_2/K\alpha_1$  intensity ratios for elements with  $13 \leq Z \leq 99$ , the former obtained using the MCDF method.

| Z  | Semi-empirical | Theoretical (MCDFGME) | Z  | Semi-empirical | Theoretical (MCDFGME) |
|----|----------------|-----------------------|----|----------------|-----------------------|
| 13 | 0.5097         | --                    | 57 | 0.5437         | --                    |
| 14 | 0.5097         | --                    | 58 | 0.5453         | --                    |
| 15 | 0.5098         | --                    | 59 | 0.5470         | --                    |
| 16 | 0.5098         | 0.4900                | 60 | 0.5487         | --                    |
| 17 | 0.5100         | --                    | 61 | 0.5505         | --                    |
| 18 | 0.5101         | 0.5056                | 62 | 0.5523         | --                    |
| 19 | 0.5103         | 0.5041                | 63 | 0.5541         | --                    |
| 20 | 0.5105         | --                    | 64 | 0.5560         | --                    |
| 21 | 0.5108         | --                    | 65 | 0.5579         | --                    |
| 22 | 0.5110         | 0.5057                | 66 | 0.5598         | --                    |
| 23 | 0.5114         | --                    | 67 | 0.5618         | --                    |
| 24 | 0.5117         | 0.4880                | 68 | 0.5638         | --                    |
| 25 | 0.5121         | --                    | 69 | 0.5659         | --                    |
| 26 | 0.5125         | 0.4942                | 70 | 0.5680         | --                    |
| 27 | 0.5129         | --                    | 71 | 0.5702         | --                    |
| 28 | 0.5134         | 0.5118                | 72 | 0.5723         | --                    |
| 29 | 0.5139         | 0.5112                | 73 | 0.5746         | --                    |
| 30 | 0.5145         | 0.5131                | 74 | 0.5768         | --                    |
| 31 | 0.5151         | --                    | 75 | 0.5791         | --                    |
| 32 | 0.5157         | 0.5147                | 76 | 0.5814         | --                    |
| 33 | 0.5164         | 0.5146                | 77 | 0.5838         | --                    |
| 34 | 0.5171         | 0.5156                | 78 | 0.5862         | --                    |
| 35 | 0.5178         | --                    | 79 | 0.5886         | --                    |
| 36 | 0.5186         | 0.5183                | 80 | 0.5910         | 0.5895                |
| 37 | 0.5194         | --                    | 81 | 0.5935         | --                    |
| 38 | 0.5202         | --                    | 82 | 0.5960         | --                    |
| 39 | 0.5211         | --                    | 83 | 0.5986         | 0.5953                |
| 40 | 0.5220         | 0.5223                | 84 | 0.6011         | --                    |
| 41 | 0.5230         | --                    | 85 | 0.6037         | --                    |
| 42 | 0.5240         | --                    | 86 | 0.6063         | 0.6056                |
| 43 | 0.5250         | --                    | 87 | 0.6090         | --                    |
| 44 | 0.5261         | --                    | 88 | 0.6116         | --                    |
| 45 | 0.5272         | --                    | 89 | 0.6143         | --                    |
| 46 | 0.5284         | --                    | 90 | 0.6170         | --                    |
| 47 | 0.5296         | --                    | 91 | 0.6197         | --                    |
| 48 | 0.5308         | 0.5315                | 92 | 0.6225         | --                    |
| 49 | 0.5321         | --                    | 93 | 0.6252         | --                    |
| 50 | 0.5334         | 0.5334                | 94 | 0.6280         | --                    |
| 51 | 0.5347         | --                    | 95 | 0.6308         | --                    |
| 52 | 0.5361         | 0.5361                | 96 | 0.6336         | --                    |
| 53 | 0.5375         | --                    | 97 | 0.6364         | --                    |
| 54 | 0.5390         | --                    | 98 | 0.6392         | --                    |
| 55 | 0.5405         | --                    | 99 | 0.6420         | --                    |
| 56 | 0.5421         | --                    |    |                |                       |

**Table 10.** Theoretical and semi-empirical  $K\beta_1 / K\alpha_1$  intensity ratios for elements with  $16 \leq Z \leq 96$ , the former obtained using the MCDF method.

| Z  | Semi-empirical | Theoretical (MCDFGME) | Z  | Semi-empirical | Theoretical (MCDFGME) |
|----|----------------|-----------------------|----|----------------|-----------------------|
| 16 | --             | 0.0813                | 57 | 0.3007         | --                    |
| 17 | --             | --                    | 58 | 0.3032         | --                    |
| 18 | --             | 0.1569                | 59 | 0.3055         | --                    |
| 19 | --             | 0.1555                | 60 | 0.3078         | --                    |
| 20 | --             | --                    | 61 | 0.3100         | --                    |
| 21 | --             | --                    | 62 | 0.3121         | --                    |
| 22 | --             | 0.1796                | 63 | 0.3142         | --                    |
| 23 | --             | --                    | 64 | 0.3162         | --                    |
| 24 | 0.1631         | 0.1794                | 65 | 0.3181         | --                    |
| 25 | 0.1690         | --                    | 66 | 0.3200         | --                    |
| 26 | 0.1747         | 0.2008                | 67 | 0.3218         | --                    |
| 27 | 0.1804         | --                    | 68 | 0.3236         | --                    |
| 28 | 0.1860         | 0.1977                | 69 | 0.3253         | --                    |
| 29 | 0.1915         | 0.1956                | 70 | 0.3270         | --                    |
| 30 | 0.1969         | 0.2065                | 71 | 0.3286         | --                    |
| 31 | 0.2022         | --                    | 72 | 0.3302         | --                    |
| 32 | 0.2073         | 0.2167                | 73 | 0.3318         | --                    |
| 33 | 0.2124         | 0.2154                | 74 | 0.3333         | --                    |
| 34 | 0.2174         | 0.2205                | 75 | 0.3348         | --                    |
| 35 | 0.2222         | --                    | 76 | 0.3363         | --                    |
| 36 | 0.2270         | 0.2323                | 77 | 0.3377         | --                    |
| 37 | 0.2316         | --                    | 78 | 0.3391         | --                    |
| 38 | 0.2361         | --                    | 79 | 0.3406         | --                    |
| 39 | 0.2405         | --                    | 80 | 0.3420         | 0.3406                |
| 40 | 0.2447         | 0.2491                | 81 | 0.3434         | --                    |
| 41 | 0.2489         | --                    | 82 | 0.3447         | --                    |
| 42 | 0.2529         | --                    | 83 | 0.3461         | 0.3444                |
| 43 | 0.2569         | --                    | 84 | 0.3475         | --                    |
| 44 | 0.2607         | --                    | 85 | 0.3489         | --                    |
| 45 | 0.2644         | --                    | 86 | 0.3503         | 0.3496                |
| 46 | 0.2680         | --                    | 87 | 0.3516         | --                    |
| 47 | 0.2715         | --                    | 88 | 0.3530         | --                    |
| 48 | 0.2748         | 0.2762                | 89 | 0.3545         | --                    |
| 49 | 0.2781         | --                    | 90 | 0.3559         | --                    |
| 50 | 0.2813         | 0.2830                | 91 | 0.3573         | --                    |
| 51 | 0.2843         | --                    | 92 | 0.3588         | --                    |
| 52 | 0.2873         | 0.2821                | 93 | 0.3602         | --                    |
| 53 | 0.2902         | --                    | 94 | 0.3617         | --                    |
| 54 | 0.2930         | --                    | 95 | 0.3632         | --                    |
| 55 | 0.2956         | --                    | 96 | 0.3648         | --                    |
| 56 | 0.2982         | --                    |    |                |                       |

**Table 11.** Theoretical and semi-empirical  $K\beta_2/K\alpha_1$  intensity ratios for elements with  $30 \leq Z \leq 94$ , the former obtained using the MCDF method.

| Z  | Semi-empirical | Theoretical (MCDFGME) | Z  | Semi-empirical | Theoretical (MCDFGME) |
|----|----------------|-----------------------|----|----------------|-----------------------|
| 30 | 0.0060         | --                    | 63 | 0.0785         | --                    |
| 31 | 0.0074         | --                    | 64 | 0.0798         | --                    |
| 32 | 0.0090         | 0.0045                | 65 | 0.0810         | --                    |
| 33 | 0.0108         | 0.0084                | 66 | 0.0822         | --                    |
| 34 | 0.0127         | 0.0128                | 67 | 0.0833         | --                    |
| 35 | 0.0148         | --                    | 68 | 0.0843         | --                    |
| 36 | 0.0170         | 0.0227                | 69 | 0.0852         | --                    |
| 37 | 0.0193         | --                    | 70 | 0.0861         | --                    |
| 38 | 0.0217         | --                    | 71 | 0.0870         | --                    |
| 39 | 0.0242         | --                    | 72 | 0.0878         | --                    |
| 40 | 0.0268         | 0.0351                | 73 | 0.0886         | --                    |
| 41 | 0.0295         | --                    | 74 | 0.0894         | --                    |
| 42 | 0.0321         | --                    | 75 | 0.0901         | --                    |
| 43 | 0.0349         | --                    | 76 | 0.0908         | --                    |
| 44 | 0.0376         | --                    | 77 | 0.0915         | --                    |
| 45 | 0.0403         | --                    | 78 | 0.0923         | --                    |
| 46 | 0.0430         | --                    | 79 | 0.0930         | --                    |
| 47 | 0.0457         | --                    | 80 | 0.0938         | 0.0823                |
| 48 | 0.0483         | 0.0483                | 81 | 0.0946         | --                    |
| 49 | 0.0509         | --                    | 82 | 0.0954         | --                    |
| 50 | 0.0534         | 0.0529                | 83 | 0.0962         | 0.0847                |
| 51 | 0.0558         | --                    | 84 | 0.0972         | --                    |
| 52 | 0.0582         | 0.0569                | 85 | 0.0981         | --                    |
| 53 | 0.0605         | --                    | 86 | 0.0992         | 0.0874                |
| 54 | 0.0627         | --                    | 87 | 0.1003         | --                    |
| 55 | 0.0649         | --                    | 88 | 0.1015         | --                    |
| 56 | 0.0669         | 0.0628                | 89 | 0.1028         | --                    |
| 57 | 0.0688         | --                    | 90 | 0.1043         | --                    |
| 58 | 0.0707         | --                    | 91 | 0.1058         | --                    |
| 59 | 0.0724         | --                    | 92 | 0.1075         | --                    |
| 60 | 0.0741         | --                    | 93 | 0.1093         | --                    |
| 61 | 0.0756         | --                    | 94 | 0.1112         | --                    |
| 62 | 0.0771         | --                    |    |                |                       |

**Table 12.** Theoretical and semi-empirical  $K\beta_2/K\alpha_1$  intensity ratios for elements with  $34 \leq Z \leq 96$ , the former obtained using the MCDF method.

| Z  | Semi-empirical | Theoretical (MCDFGME) | Z  | Semi-empirical | Theoretical (MCDFGME) |
|----|----------------|-----------------------|----|----------------|-----------------------|
| 32 | --             | 0.00454               | 65 | 0.0768         | --                    |
| 33 | --             | 0.00838               | 66 | 0.0778         | --                    |
| 34 | --             | 0.01277               | 67 | 0.0789         | --                    |
| 35 | --             | --                    | 68 | 0.0799         | --                    |
| 36 | --             | 0.02272               | 69 | 0.0809         | --                    |
| 37 | --             | --                    | 70 | 0.0819         | --                    |
| 38 | --             | --                    | 71 | 0.0828         | --                    |
| 39 | --             | --                    | 72 | 0.0838         | --                    |
| 40 | 0.0361         | 0.0351                | 73 | 0.0848         | --                    |
| 41 | 0.0382         | --                    | 74 | 0.0858         | --                    |
| 42 | 0.0403         | --                    | 75 | 0.0868         | --                    |
| 43 | 0.0424         | --                    | 76 | 0.0878         | --                    |
| 44 | 0.0444         | --                    | 77 | 0.0889         | --                    |
| 45 | 0.0464         | --                    | 78 | 0.0900         | --                    |
| 46 | 0.0484         | --                    | 79 | 0.0911         | --                    |
| 47 | 0.0503         | --                    | 80 | 0.0923         | --                    |
| 48 | 0.0522         | 0.0485                | 81 | 0.0935         | 0.0988                |
| 49 | 0.0541         | --                    | 82 | 0.0948         | --                    |
| 50 | 0.0559         | 0.0547                | 83 | 0.0962         | --                    |
| 51 | 0.0576         | --                    | 84 | 0.0976         | 0.1034                |
| 52 | 0.0593         | 0.0613                | 85 | 0.0991         | --                    |
| 53 | 0.0610         | --                    | 86 | 0.1007         | --                    |
| 54 | 0.0626         | --                    | 87 | 0.1025         | 0.1081                |
| 55 | 0.0641         | --                    | 88 | 0.1043         | --                    |
| 56 | 0.0656         | 0.0734                | 89 | 0.1062         | --                    |
| 57 | 0.0670         | --                    | 90 | 0.1083         | --                    |
| 58 | 0.0684         | --                    | 91 | 0.1105         | --                    |
| 59 | 0.0697         | --                    | 92 | 0.1128         | --                    |
| 60 | 0.0710         | --                    | 93 | 0.1153         | --                    |
| 61 | 0.0722         | --                    | 94 | 0.1180         | --                    |
| 62 | 0.0734         | --                    | 95 | 0.1209         | --                    |
| 63 | 0.0746         | --                    | 96 | 0.1240         | --                    |
| 64 | 0.0757         | --                    |    |                |                       |

**Table 13.** Theoretical and semi-empirical  $K\beta_2/K\beta_1$  intensity ratios for elements with  $32 \leq Z \leq 92$ , the former obtained using the MCDF method.

| Z  | Semi-empirical | Theoretical (MCDFGME) | Z  | Semi-empirical | Theoretical (MCDFGME) |
|----|----------------|-----------------------|----|----------------|-----------------------|
| 32 | --             | 0.0209                | 63 | 0.2600         | --                    |
| 33 | --             | 0.0389                | 64 | 0.2626         | --                    |
| 34 | --             | 0.0579                | 65 | 0.2650         | --                    |
| 35 | --             | --                    | 66 | 0.2672         | --                    |
| 36 | --             | 0.0978                | 67 | 0.2693         | --                    |
| 37 | --             | --                    | 68 | 0.2711         | --                    |
| 38 | --             | --                    | 69 | 0.2728         | --                    |
| 39 | --             | --                    | 70 | 0.2744         | --                    |
| 40 | 0.1373         | 0.1409                | 71 | 0.2758         | --                    |
| 41 | 0.1449         | --                    | 72 | 0.2770         | --                    |
| 42 | 0.1523         | --                    | 73 | 0.2781         | --                    |
| 43 | 0.1596         | --                    | 74 | 0.2790         | --                    |
| 44 | 0.1667         | --                    | 75 | 0.2798         | --                    |
| 45 | 0.1737         | --                    | 76 | 0.2806         | --                    |
| 46 | 0.1804         | --                    | 77 | 0.2812         | --                    |
| 47 | 0.1870         | --                    | 78 | 0.2817         | --                    |
| 48 | 0.1933         | 0.1758                | 79 | 0.2821         | --                    |
| 49 | 0.1994         | --                    | 80 | 0.2824         | 0.2900                |
| 50 | 0.2053         | 0.1932                | 81 | 0.2826         | --                    |
| 51 | 0.2109         | --                    | 82 | 0.2828         | --                    |
| 52 | 0.2163         | 0.2173                | 83 | 0.2829         | 0.3002                |
| 53 | 0.2215         | --                    | 84 | 0.2830         | --                    |
| 54 | 0.2264         | --                    | 85 | 0.2830         | --                    |
| 55 | 0.2311         | --                    | 86 | 0.2830         | 0.3092                |
| 56 | 0.2355         | 0.2479                | 87 | 0.2830         | --                    |
| 57 | 0.2397         | --                    | 88 | 0.2829         | --                    |
| 58 | 0.2436         | --                    | 89 | 0.2828         | --                    |
| 59 | 0.2473         | --                    | 90 | 0.2827         | --                    |
| 60 | 0.2508         | --                    | 91 | 0.2827         | --                    |
| 61 | 0.2541         | --                    | 92 | 0.2826         | --                    |
| 62 | 0.2571         | --                    |    |                |                       |

**Table 14.** Theoretical and semi-empirical  $K\beta_3/K\beta_1$  intensity ratios for elements with  $18 \leq Z \leq 99$ , the former obtained using the MCDF method.

| Z  | Semi-empirical | Theoretical (MCDFGME) | Z  | Semi-empirical | Theoretical (MCDFGME) |
|----|----------------|-----------------------|----|----------------|-----------------------|
| 18 | --             | 0.5058                | 59 | 0.5164         | --                    |
| 19 | --             | 0.4959                | 60 | 0.5164         | --                    |
| 20 | --             | --                    | 61 | 0.5165         | --                    |
| 21 | --             | --                    | 62 | 0.5165         | --                    |
| 22 | --             | 0.3324                | 63 | 0.5165         | --                    |
| 23 | --             | --                    | 64 | 0.5165         | --                    |
| 24 | --             | 0.2342                | 65 | 0.5166         | --                    |
| 25 | --             | --                    | 66 | 0.5166         | --                    |
| 26 | --             | 0.2760                | 67 | 0.5166         | --                    |
| 27 | --             | --                    | 68 | 0.5166         | --                    |
| 28 | --             | --                    | 69 | 0.5167         | --                    |
| 29 | --             | 0.5135                | 70 | 0.5167         | --                    |
| 30 | --             | 0.5112                | 71 | 0.5168         | --                    |
| 31 | --             | --                    | 72 | 0.5169         | --                    |
| 32 | --             | 0.5082                | 73 | 0.5170         | --                    |
| 33 | --             | 0.5060                | 74 | 0.5171         | --                    |
| 34 | --             | 0.5099                | 75 | 0.5172         | --                    |
| 35 | --             | --                    | 76 | 0.5174         | --                    |
| 36 | --             | 0.5125                | 77 | 0.5176         | --                    |
| 37 | --             | --                    | 78 | 0.5178         | --                    |
| 38 | --             | --                    | 79 | 0.5181         | --                    |
| 39 | 0.5097         | --                    | 80 | 0.5184         | 0.5170                |
| 40 | 0.5104         | 0.5132                | 81 | 0.5187         | --                    |
| 41 | 0.5111         | --                    | 82 | 0.5191         | --                    |
| 42 | 0.5118         | --                    | 83 | 0.5195         | 0.5159                |
| 43 | 0.5123         | --                    | 84 | 0.5199         | --                    |
| 44 | 0.5129         | --                    | 85 | 0.5204         | --                    |
| 45 | 0.5134         | --                    | 86 | 0.5210         | 0.5152                |
| 46 | 0.5138         | --                    | 87 | 0.5215         | --                    |
| 47 | 0.5142         | --                    | 88 | 0.5222         | --                    |
| 48 | 0.5145         | 0.5148                | 89 | 0.5229         | --                    |
| 49 | 0.5149         | --                    | 90 | 0.5236         | --                    |
| 50 | 0.5151         | 0.5163                | 91 | 0.5244         | --                    |
| 51 | 0.5154         | --                    | 92 | 0.5253         | --                    |
| 52 | 0.5156         | 0.5345                | 93 | 0.5262         | --                    |
| 53 | 0.5158         | --                    | 94 | 0.5272         | --                    |
| 54 | 0.5159         | --                    | 95 | 0.5283         | --                    |
| 55 | 0.5161         | --                    | 96 | 0.5294         | --                    |
| 56 | 0.5162         | --                    | 97 | 0.5306         | --                    |
| 57 | 0.5163         | --                    | 98 | 0.5319         | --                    |
| 58 | 0.5163         | --                    | 99 | 0.5332         | --                    |