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Measurement of K X-ray intensity ratios in Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu and Zn employing carbon and nitrogen projectiles – VTT method

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Abstract. A method is suggested to effect the self absorption correction in a different way to estimate the K X-ray intensity ratios particularly when heavy ions are used as projectiles. Employing this method, the K_β/K_α intensity ratios are measured in some $3d$ shell elements by using Carbon and Nitrogen ions as exciting agents. The K_β/K_α intensity ratios thus obtained in the present work are compared with the intensity ratios due to some previous authors and also with Scofield theoretical values.

PACS. 34.90.+q Other topics in atomic and molecular collision processes and interactions – 34.50.Fa Electronic excitation and ionization of atoms (including beam-foil excitation and ionization) – 32.30.Rj X-ray spectra

1 Introduction

An accurate measurement of the relative intensities of K X-rays is of importance to understand the atomic inner shell ionization process and to test the relevant existing theories. The K X-ray intensity ratios have been measured by several authors [1–28] by creating K-shell vacancies by several types of projectiles – photons [1–6], X-rays [7,8], electrons [9], protons [10–12] or heavy ions [13–17].

In evaluating the K X-ray intensities ratios, correction due to self absorption is very important. Knowing the intensities of K_α and K_β X-ray components and the corresponding attenuation coefficients, the self absorption correction has been applied using the standard formula

$$I = I_0(1 - \mathrm{e}^{-\mu x}).$$

Here, I represent the intensity of X-rays after passing through an absorber of thickness x, I_0 represent the intensity of X-rays before absorption and μ is the attenuation coefficient corresponding to the energy. When heavy ions are used as projectiles and solid state detectors are used for X-ray detection, it is not possible to apply self absorption correction as mentioned above to determine the K_β/K_α intensity ratios. The reason is as follows.

With heavy ions, multiple ionization takes place resulting a small increase in the X-ray energies. Burch *et al.* [29] have reported an increase of about 54 eV in K_α X-ray component and about 150 eV in K_β X-ray component by using oxygen ions as projectiles. The X-rays with normal energies are emitted from the atoms with single hole excitation while the X-rays with increased energy (due to energy shift) are emitted from the multiply ionized atoms. The energies of K_α (normal), K_β (normal) and K_α (increased energy) X-ray components lie below the K-absorption edge of that element while the energy of K_β X-ray components with increase energy lie above the K-absorption edge. Hence the energy shifted K_β X-ray component have high attenuation coefficient compared with that for normal K_β X-ray component. In consequence, the normal and energy shifted K_β X-ray components will be absorbed differently. In this situation, the self-absorption correction has been applied for normal as well as energy shifted X-ray components separately. This is possible only when the intensities of normal and energy shifted X-ray components are known separately. In the measurements, due to better efficiency, solid state detectors are much useful than crystal spectrometers. But due to limited resolution of the solid state detectors, it is not possible to resolve the normal and energy shifted X-ray components separately. Thus, it is not possible to apply a self absorption correction. As a result, it is not possible to determine the K_β/K_α intensity ratios correctly.

To overcome the above difficulty, a Variable Target Thickness method (VTT) is suggested and using the method, the K_β/K_α intensity ratios are measured in some $3d$ shell elements using Si(Li) detector. In the present work, carbon and nitrogen ions are used as projectiles.

2 Method

In VTT method, for a given element, targets of different thickness are employed. The K X-ray spectrum of each

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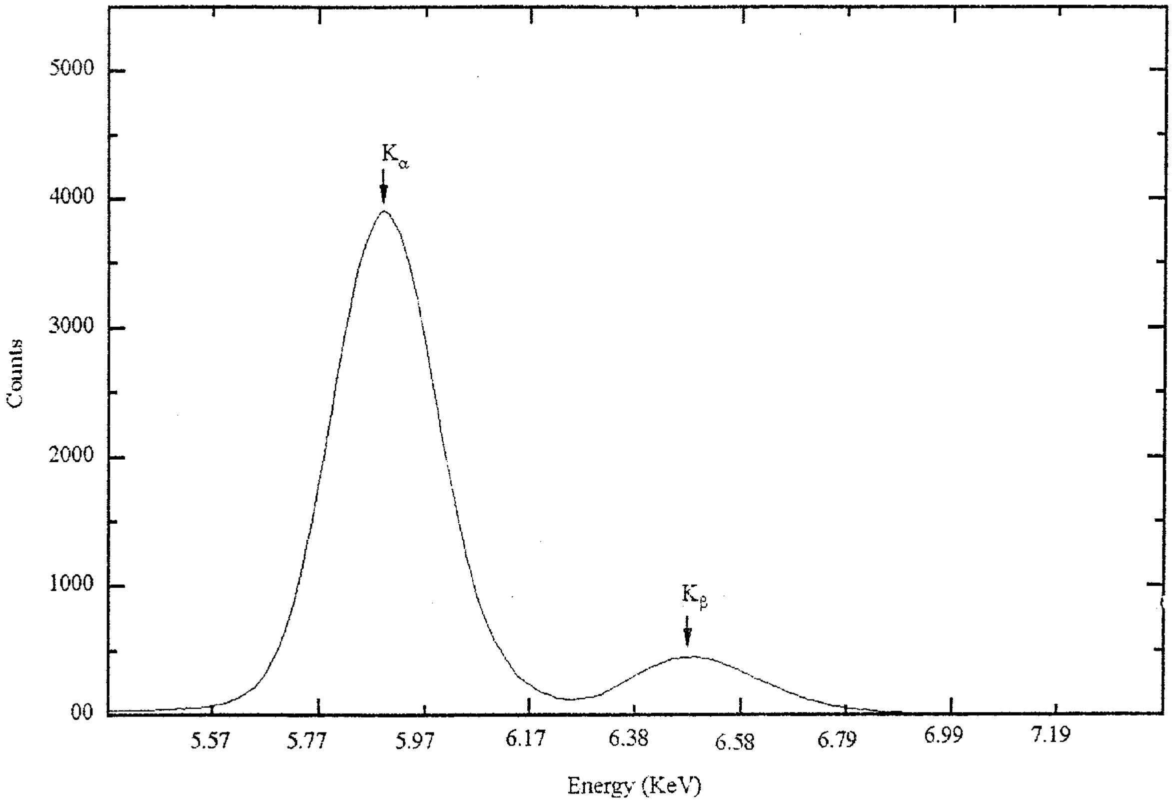

Fig. 1. The K X-ray spectrum of manganese excited by carbon ions.

target is recorded with Si(Li) detector using heavy ions as projectiles. The intensities of K_α and K_β X-ray components are determined and the K_β/K_α intensity ratio for each target thickness is estimated. The K_β/K_α values thus obtained are still uncorrected for self-absorption. The K_β/K_α intensity ratios corresponding to different thickness of the same element are plotted against the corresponding target thickness. The resultant points of the graph are extrapolated to "zero thickness". The K_β/K_α value thus obtained for "zero thickness" is the actual K_β/K_α value of that element.

3 Experimental details

In the present work, using the above method, the K_β/K_α intensity ratios are measured in elements Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu and Zn with 0.83 MeV/amu carbon ion projectiles and in elements Ca, Ti, V, Cr, and Mn with 0.89 MeV/amu nitrogen ions. Some of the elements that are used in the present work are available in the form of compounds. The thickness of different targets that are used in the present work varies from 0.5 mg/cm^2 to 4 mg/cm^2.

The present experiments were carried out using 3MV tandem pelletron accelerator facility at the Institute of Physics, Bhubaneswar. The collimated beam of C and N ions of diameter 1.5 mm were directed on to the target. The target is kept at an angle of 45° to the beam direction. The emitted K X-rays are passed through a 3.5 mg/cm^2 mylar window, a 5 cm air gap and 0.012 mm thick Be window. The Si(Li) detector is kept at angle of 90° to the beam direction. The resolution of the detector is 160 eV (FWHM) at 5.9 keV photon energy. The uncertainty in counting statistics is less than 1%. A typical K X-ray spectrum of manganese element excited with carbon ions is shown in Figure 1.

4 Data analysis

The areas under the K_α and K_β X-ray components were obtained using a fitting routine. The areas thus obtained were corrected for detector efficiency.

The efficiency of the Si(Li) detector was theoretically calculated as described by Padhi *et al.* [30]. From these intensities, the K_β/K_α ratios were determined for targets of different thickness and plotted against the corresponding thickness value. A typical graph thus obtained for manganese element with carbon ions is shown in Figure 2. Through extrapolation, the K_β/K_α value corresponding to "zero thickness" was determined... The K_β/K_α value thus obtained for different elements using VTT method with C ions and N ions are given in Table 1. In the same table, the theoretical values due to Scofield [31] were also given.

The K_β/K_α intensity ratios obtained in the present work are associated with an over all uncertainty of about 3% which is contributed cumulatively by individual

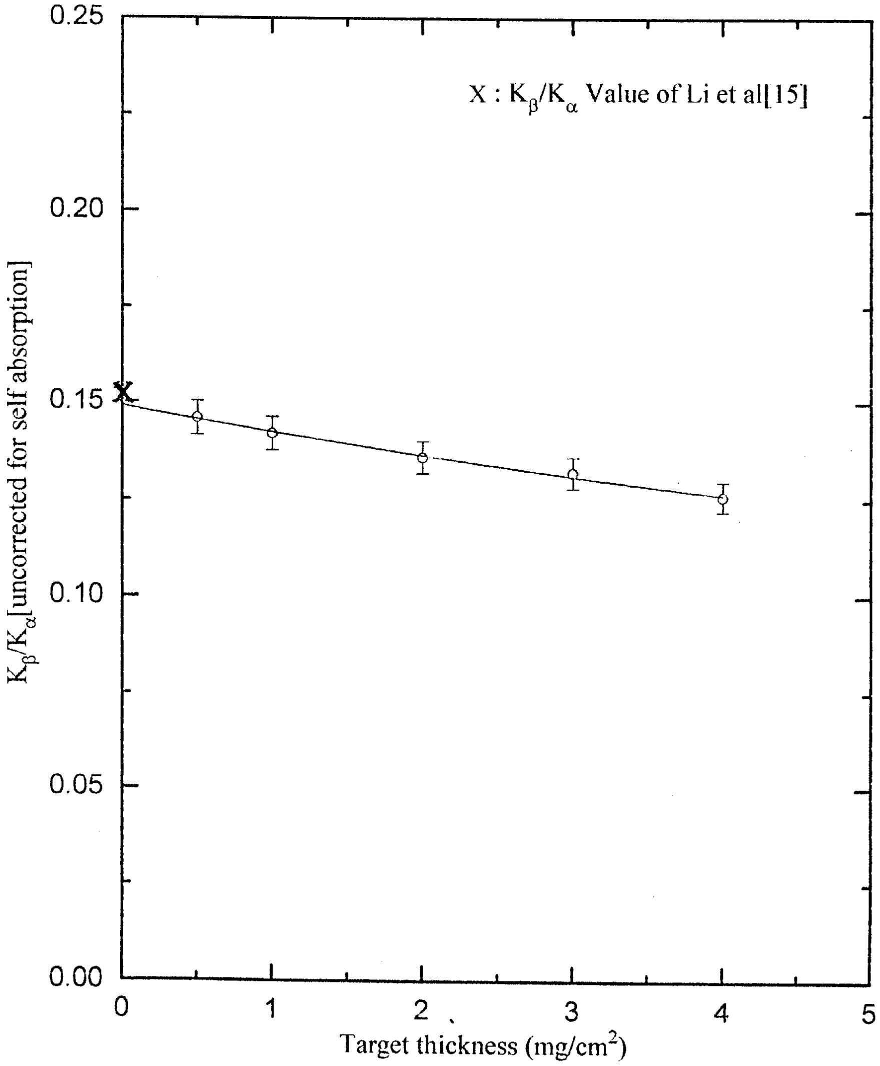

Fig. 2. The K_β/K_α intensity ratios of manganese excited by carbon ions extrapolated to zero thickness.

Table 1. Experimental K_β/K_α intensity ratios of different elements due to carbon and nitrogen ions.

element	K_β/K_α (experimental)		K_β/K_α (theory) Scofield [31]
	carbon ions	nitrogen ions	
Ca	0.183(4)	0.185(5)	0.1315
Ti	0.162(4)	0.166(4)	0.1355
V	0.152(4)	0.157(4)	0.1367
Cr	0.156(4)	0.159(4)	0.1337
Mn	0.149(4)	0.154(4)	0.1385
Fe	0.151(4)		0.1391
Co	0.148(4)		
Ni	0.160(4)		0.1401
Cu	0.159(4)		0.1379
Zn	0.163(4)		0.1410

uncertainties due to detector efficiency, counting statistics and target thickness measurement.

5 Results and discussion

Li *et al.* [15] have measured the K_β/K_α intensity ratios in some of the elements ranging from K to Ag using He and C ions with different energies. Awaya *et al.* [16] also measured the K X-ray intensity ratios using He and N ions. They employed Si(Li) detector in their measurements. Li *et al.* [15] used targets of thickness ranging from 20–135 μg/cm^2 and Awaya *et al.* [16] used targets of thickness ranging from 22–350 μg/cm^2. To these thin targets, they neglected the self-absorption correction.

The VTT technique proposed in the present work has the advantage that thick targets can be used which facilitate good counting statistics with a short duration of data collection.

The K_β/K_α values obtained in the present work due to heavy ion excitation are much higher than the K_β/K_α values obtained with photon or X-ray excitation as well as Scofield [31] theoretical values. This is evident from Table 1. The elements used in the present work are available in the form of chemical compounds. Some of the previous authors [2–5,7] observed that the K_β/K_α values obtained with different chemical compounds of the same element are higher by about 3 to 4% than the K_β/K_α values due to pure elements. As in the present work, since the elements used are in the form of compounds, the observed deviations may be partly due to the effect of chemical environment and partly due to the phenomenon of multiple ionization. In order to investigate the deviations of K_β/K_α intensity ratios due to multiple ionization phenomena, it is necessary to determine the ratios in pure elements also.

The energies of C and N ions employed in the present work are 0.83 and 0.89 MeV/amu respectively. Therefore, it is not possible to directly compare the present K_β/K_α values with those due to Li *et al.* [15], who employed C ions having energies above 2.35 MeV/amu. From the data of Li *et al.* [15], it is evident that the K_β/K_α intensity ratio of a particular element increases with the decrease of projectile energy. Hence, it is expected that the K_β/K_α intensity ratios obtained in the present work at projectile energy of 0.83 MeV/amu may be higher than the values obtained by Li *et al.* [15] at a projectile energy of 2.35 MeV/amu. However, due to large experimental uncertainties, such difference is not observed.

Li *et al.* [15] calculated the functional dependence of K_β/K_α intensity ratios on the initial inner shell vacancy configuration. From their calculations, it is noticed that the K_β/K_α intensity ratio is a strongly increasing function of the number of simultaneous $2p$ (L-shell) vacancies and a slowly decreasing function of the number of simultaneous $3p$ (M-shell) vacancies. The higher K_β/K_α values obtained in the present work due to 0.83 Mev/amu carbon and nitrogen ions suggest that at this ion energies, production of simultaneous vacancies in the L-shell (in addition to K-vacancy) is more probable than the production of simultaneous vacancies in M-shell.

6 Conclusion

In the present work, a method is suggested to avoid a self-absorption correction when measuring the K_β/K_α values using heavy ions as projectiles and thick targets.

The K_β/K_α values obtained in the present work for heavy ions are much higher than Scofield theoretical values as well as the values due to photon excitation. These large deviations are mainly due to the phenomenon of multiple ionization process (large extent) and due to the phenomenon of chemical effects (small extent).

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