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Measurement of K x-ray fluorescence parameters in elements with $24 \leq Z \leq 65$ in an external magnetic field

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HIGHLIGHTS

- ► In the presence of the external magnetic field, K shell fluorescence parameters can change.
- ► These parameters are different for paramagnetic, ferromagnetic and diamagnetic materials.
- ► For $B=0$, the measured K shell fluorescence parameters are in good agreement with the experimental and theoretical data in literature.
- ► K shell fluorescence parameters for the same magnitude but opposite direction of the magnetic field are symmetrical.

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ABSTRACT

The effect of the external magnetic field has been investigated on the K x-ray fluorescence parameters ($K\alpha$, $K\beta$ and total K x-rays fluorescence cross sections, fluorescence yields, $I_{K\beta}/I_{K\alpha}$ intensity ratios and K shell level widths) for 25 elements with $24 \leq Z \leq 65$ by using an energy dispersive x-ray fluorescence spectrometer. The samples were irradiated by using the gamma rays of 59.537 keV emitted from ^{241}Am radioisotope source of 100 mCi. The external magnetic fields have been applied in two opposite directions and the magnitude of the external magnetic field has been fixed at +0.75 T and −0.75 T. For $B=0$, the measured K shell fluorescence parameters have been compared with the experimental and theoretical data in literature. The results show that the fluorescence parameters such as fluorescence cross section, fluorescence yield, intensity ratio, spectral linewidth and radiation rates can change when the irradiation is conducted in the external magnetic field.

1. Introduction

As soon as a photon strikes to an atom a characteristic x-ray is arisen from the transition between two allowed energy levels emitted by the atom. The energy of this x-ray is equal to the differences between the energies of these allowed energy levels. The transition of an L shell electron dropping into the K shell is termed a $K\alpha$ transition, while an M shell electron dropping into the K shell is $K\beta$ transition. X-ray fluorescence parameters such as cross section, yield, intensity ratio and level width are very important in understanding the ionization of atoms as well as for non-destructive elemental analysis in several fields such as material science, medical physics, industry and environmental science. Besides, these parameters are needed to develop more reliable theoretical models for describing the fundamental inner shell ionization processes.

K shell fluorescence yields for different elements have been investigated for many years. Bambynek et al. (1972) in a review article have fitted their collection of selected most reliable experimental values in the atomic range $13 \leq Z \leq 92$. Krause et al. (1978) compiled K shell fluorescence yields adopted values for elements $5 \leq Z \leq 110$. Hubbell et al. (1994) have compiled more recent experimental values. Balakrishna et al. (1994) measured K shell fluorescence yields using HPGe low energy photon detector for some rare earth and heavy elements at 59.5 and 279.2 keV gamma rays. Horakeri et al. (1998) determined K shell fluorescence yields using a simple method for some elements in the atomic range $62 \leq Z \leq 83$ at 123.6 and 320 keV energies. Bhan et al. (1981), Garg et al. (1985), Casnati et al. (1991) and Kumar et al. (1987) have determined the K x-ray production cross sections for medium Z elements. K shell fluorescence cross sections and yields of 14 elements in the atomic range $25 \leq Z \leq 47$ were determined by Durak and Özdemir (2001). Gowda and Sanjeevaiah (1974) measured K shell photoelectric cross sections for Cu, Zr, Ag, Sn, Ta, Au and Pb elements at excitation with 279.1 and 411.8 keV gamma rays. $K\alpha$ and $K\beta$ fluorescence cross sections for elements in the range $44 \leq Z \leq 68$ at 59.5 keV have been studied by Budak et al. (1999) Seven (2002) measured photon-induced K x-ray cross sections for some heavy elements at 78.706 keV gamma rays. Karabulut et al. (1999) have measured $K\alpha$ and $K\beta$ x-ray fluorescence cross sections in the

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atomic region $26 \leq Z \leq 42$ excited by 59.5 keV photons. Ertuğral et al. (2007) measured $I_{K\beta}/I_{K\alpha}$ x-ray intensity ratios for elements in the range $16 \leq Z \leq 92$ excited by 5.9, 59.5 and 123.6 keV photons. Baydaş et al. (2003) have measured $I_{K\beta}/I_{K\alpha}$ x-ray intensity ratios of Ti, V and Cr in halogen compounds versus excitation energy in the interval 5.5–12.1 keV. Han et al. (2007) have measured K x-ray fluorescence cross sections, fluorescence yields and intensity ratios for some elements in the atomic range $22 \leq Z \leq 68$. Demir and Şahin (2007a, 2007b) Nowadays, the K x-ray production cross sections and some atomic parameters in an external magnetic field for Nd, Eu, Gd, Dy and Ho have been determined.

The elementary physics explains the behavior of a magnetic dipole of moment μ_l when placed in magnetic field B. The dipole experiences a torque ($\vec{\tau} = \vec{\mu}_l \times \vec{B}$) tending to align the dipole with the field, and then, associated with this torque, there is a potential energy of orientation:

$$\Delta E = -\vec{\mu}_l . \vec{B} \tag{1}$$

According to the quantum theory, spectral lines arise from transitions of electron between allowed energy levels within the atom, and the frequency of the line is proportional to the energy difference between the initial and final levels. Slight differences in energy are associated with different orientations of atom in the magnetic field.

In the presence of a magnetic field, the elementary magnetic dipoles, whether permanent or induced, set up a field of induction of their own that modify the original field. The paramagnetic materials are weakly attracted by the field. The ferromagnetic materials have a large and positive susceptibility to the external magnetic field, while diamagnetic materials have a weak and negative susceptibility to the magnetic field. Thus, in the presence of the external magnetic field it is expected that the K shell fluorescence parameters change and that these parameters are different for paramagnetic, ferromagnetic and diamagnetic materials.

In the present work, to find out how the atomic parameters in an external magnetic field are affected, K x-rays fluorescence cross sections, the fluorescence yields, the $I_{K\beta}/I_{K\alpha}$ intensity ratios and the level widths for paramagnetic Cr, Sr, Y, Nb, Mo, Sn, Ba, La, Ce, Sm and Tb, ferromagnetic Mn, Fe, Co, Ni and Zr, and diamagnetic Cu, Zn, As, Se, Ag, Cd, In, Sb and Te have been measured using the 59.537 keV incident photon energy in the external magnetic field of intensities ± 0.75 T. The measured values for $B=0$ were compared with the experimental and theoretical data in literature.

2. Experimental setup

The geometry of experimental setup is shown in Fig. 1. The samples were irradiated by the gamma rays of 59.537 keV emitted from a filtered point source (^{241}Am) of intensity 100 mCi and the x-rays emitted from the samples were recorded with a Si(Li) detector, having 30 mm^2 active area, 5 mm sensitive crystal depth, 6.2 mm active diameter and 0.008 mm Be window. Si(Li) detector (FWHM=180 eV at 5.90 keV) is connected a Canberra Desktop Inspector controlled with the Genie 2000 Software Program. The Canberra Desktop Inspector includes an integrated MCA for detector, an amplifier, an analog digital converter (ADC), a high voltage power supply (HVPS) and digital stabilizer. The detector was shielded by a graded filter of Pb ($\sim$4.2 mm), Fe ($\sim$1.1 mm) and Al ($\sim$1 mm) to obtain a thin beam of photons scattered in the target and to prevent undesirable radiations such as L x-rays from the Pb mask, environmental background and background arising from the scattering from the sample holder and electromagnet. Spectroscopically pure samples of thickness ranging from 0.065 to 0.392 g/cm^2 have been used for the measurement. The direct beam from the source was directly

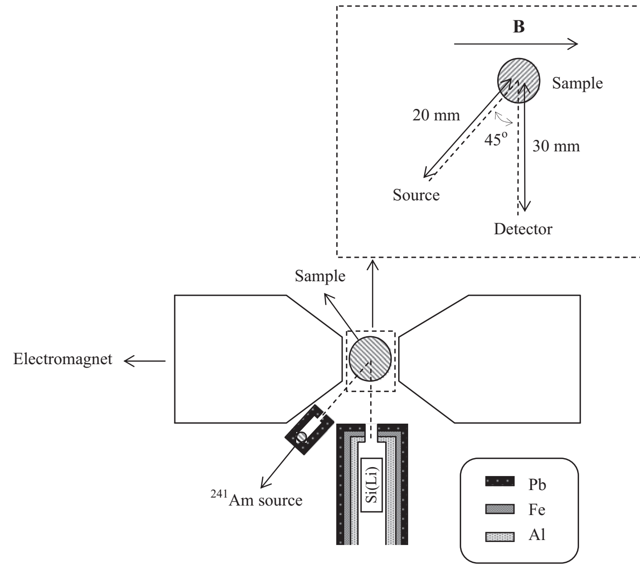

Fig. 1. Experimental setup.

incoming on the sample. The samples were placed at a 45° angle with respect to the beam from the source and fluorescent x-rays emitted in a direction perpendicular to the source were detected by a Si (Li) detector.

The samples were mounted in a sample holder placed between the pole pieces of an electromagnet capable of producing the magnetic field. Uniform and homogeneous magnetic field was applied in two opposite directions, entitled as positive and negative. The magnitude of fixed magnetic field was set to $+0.75$ T and -0.75 T. Before we started the measurement the magnetic field was applied to the samples to saturate sample magnetization. This process took 180 s and then the measurements were carried out in the external magnetic field. For each value of the magnetic field, the pulse height spectrum of K x-rays emitted from the samples was acquired in time intervals ranging from 7200 to 21600 s to obtain good statistics. The magnetic field intensity was measured five times during this time by a F.W. Bell Gauss/Teslameter. The maximum fluctuation observed in the magnetic field was about 0.008 T (1.07%).

The measurements were repeated five times for Zn, Zr, Sn and Sm to improve the statistical error. The t-test was applied to check a difference between the measured fluorescence parameters for $B=0$ and $B=+0.75$ T.

The representative K x-ray spectra of Cu in the $B=0$ and $B=+0.75$ T are shown in Fig. 2. The peak areas under the characteristic x-rays were determined by using the Nonlinear Least Square Fitting including a module by fitting the peaks by an Exponential Modified Gaussian (EM Gauss[1]). Partly overlapped peaks were resolved both a software program and a method proposed by Sahin et al. (1996) to test the accuracy of the peak areas.

3. Theory

The theoretical values of $K\alpha$ and $K\beta$ x-ray fluorescence cross sections ($\sigma_{K\alpha}$ and $\sigma_{K\beta}$) were calculated using the equations

$$\sigma_{K\alpha} = \sigma_K(E) w_K f_{K\alpha} \tag{2}$$

$$\sigma_{K\beta} = \sigma_K(E) w_K f_{K\beta} \tag{3}$$

[1] EM Gauss means exponentially modified Gaussian function. The main purpose of the modified Gaussian function is to model the low-energy tail of the measured peaks especially of the $L\alpha$ line that affects directly the Ll line.