Journal of Quantitative Spectroscopy & Radiative Transfer 111 (2010) 1363–1371

Contents lists available at ScienceDirect

Journal of Quantitative Spectroscopy & Radiative Transfer

journal homepage: www.elsevier.com/locate/jqsrt

Determination of K to L shell total vacancy transfer probabilities using a weak gamma source: An alternative method

A.S. Bennal, K.M. Niranjan, N.M. Badiger *

Department of Physics, Karnatak University, Dharwad 580003, India

ARTICLE INFO

Article history:
Received 10 December 2009
Received in revised form
21 February 2010
Accepted 23 February 2010

Keywords:
X-ray fluorescence
Intensity ratio
Vacancy transfer probability

ABSTRACT

The K–L total vacancy transfer probabilities (η_{KL}) of selected elements in the atomic range $42 \leq Z \leq 82$ have been determined using a weak gamma source. The targets are excited by 123.6 keV gamma photons from a weak ^{57}Co source and K X-ray photons are measured by an ORTEC type GMX-10P HPGe detector coupled to 8 K multichannel analyzer. By measuring the K X-ray intensity ratio and K shell fluorescence yield, the K to L total vacancy transfer probabilities have been determined. Measured values have been compared with theoretical and other experimental values.

1. Introduction

The study of vacancy transfer probabilities in atoms has been of experimental as well as theoretical interest in recent years in view of their importance in processes like internal conversion of gamma rays, atomic photoelectric effect, electron capture, etc. [1–5]. In these processes, the vacancies are created in the inner shells of atoms and some of these vacancies may transfer to higher shells. Vacancies in atomic shells can also be created by using X-ray photons, synchrotron radiation, gamma radiation, or charged particles like protons and heavy ions. The present paper mainly deals with the creation of vacancies in the inner shells and transfer of these vacancies to the higher shells of atoms by using a photo-ionization method.

The vacancy produced in the K shell is filled by an electron from one of the higher shells (L, M…) through either a radiative process or a non-radiative process. In the radiative process, the X-ray photons are produced and the phenomenon is known as X-ray fluorescence. The emission of K X-ray photons due to filling of vacancies in the K shell by the higher shell electrons is known as K X-ray fluorescence. In the radiative process, a vacancy in the K shell is transferred to the L_2 or L_3 subshell. In the nonradiative process, instead of X-ray photon, an electron from a higher shell is ejected out of the atom; such electron is known as Auger electron. Therefore the total vacancy transfer probability is the sum of the radiative and nonradiative vacancy transfer probabilities. When the vacancy is created in the K shell, it is transferred to the L shell and the total K–L vacancy transfer probability η_{KL} is the sum of the radiative $\eta_{KL}(R)$ and nonradiative $\eta_{KL}(A)$ vacancy transfer probabilities. Accurate values of η_{KL} are required to test the validity of the existing atomic models.

Several investigators have calculated the vacancy transfer probabilities. Rao et al. [6] have calculated η_{KLi} (i=1,2,3…) for the elements in the range $20 \leq Z \leq 94$ by taking Auger and radiative transition values from the best fitted experimental data on fluorescence yields, intensity ratios of different components, KLX (X=L, M, N…) of Auger electrons and K X-rays. Schonfeld and Janben [7] have compiled the η_{KL} values for the elements in the atomic range $10 \leq Z \leq 100$ using a semi empirical equation.

* Corresponding author. Tel.: +91 836 2215316; fax: +91 836 2771275.
E-mail addresses: arvindbennal@gmail.com (A.S. Bennal), niranjana26@gmail.com (K.M. Niranjan), nagappa123@yahoo.co.in (N.M. Badiger).

0022-4073/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jqsrt.2010.02.012

Additionally, other works contain measurements of the vacancy transfer probabilities, η_{KL}, in atomic shells for various elements using different processes [1,2,8,9]. Normally two methods are adopted for measuring the vacancy transfer probabilities: single-reflection geometry and double-reflection geometry. In these arrangements, either gamma radiation from a strong (around 100 mCi) radioactive source, proton beam from an accelerator, or X-rays from a generator is used to excite the K X-ray photons. These K X-ray photons are detected with either a HPGe detector or a Si(Li) detector.

Ertugrul et al. [8] have determined the η_{KL} for the elements in the atomic range $23 \leq Z \leq 57$ by measuring the K shell fluorescence yield and intensity ratio. The K X-ray photons are excited in the target by 59.54 keV gamma radiations from a strong ($\sim$1.85 GBq) ^{241}Am radioactive source. Oz [10] has measured the η_{KL} values for the elements in the atomic range $25 \leq Z \leq 42$ by measuring the K X-ray intensity ratios. The K X-ray photons are excited in the target by 59.54 keV gamma radiations from a strong ($\sim$100 mCi) ^{241}Am radioactive source. Bonzi [1] has measured the radiative vacancy transfer probabilities from L_3 to M and L_3 to N shells for W, Re and Pb elemental targets. The L X-ray photons are excited by 11.00 and 13.2 keV X-ray photons from a synchrotron light source. Han et al. [11] measured the η_{KLi} (I=1,2,3) for Sm, Eu, Gd, Dy, Ho and Er by measuring L X-ray production cross sections and L shell fluorescence yields. Reyes-Herrera and Miranda [2] have measured K–L radiative vacancy transfer probabilities in some rare earth elements (Ce, Nd, Gd, Dy and Ho) by creating vacancies in the K shell using 3–4 MeV proton beams from Pelletron accelerator. Finally, Bennal and Badiger [12] have reported a new method for measuring the $\eta_{KL}(R)$ for the elemental targets of Ta, Au, Pb in a 2π geometrical configuration using a weak ($\sim$10 μCi) ^{57}Co radioactive source.

Although the total vacancy transfer data are available for medium and high Z elements using strong sources, our objective in the present paper is to show how these parameters can be determined by an alternative method which involves a weak gamma source of ^{57}Co and a 2π geometrical configuration. This method has three advantages. First, since a weak gamma source is used, source shielding and collimators are not required. Second, as whole surface area of the target is exposed to the incident photons and the detector is placed close to the target, more number of K X-ray photons are collected by the detector. Third, the number of photons falling on the target, which is crucial in η_{KL} measurements, can be determined accurately. In the present paper we report our measurements of the total vacancy transfer probabilities η_{KL} for selected elemental targets in the atomic range $42 \leq Z \leq 82$ using this method of Bennal and Badiger [12,13].

2. Theory

It is well known that a vacancy produced in an inner shell of the atom is filled through a radiative or a nonradiative process. The X-ray fluorescence is the radiative process, while the Auger and Coster Kronig transitions are nonradiative processes. The total vacancy transfer probability η_{KL} from K to L is the sum of the radiative vacancy transfer probability, $\eta_{KL}(R)$ and non-radiative vacancy transfer probability $\eta_{KL}(A)$.

$$\eta_{KL} = \eta_{KL}(R) + \eta_{KL}(A) \tag{1}$$

The radiative vacancy transfer probability, $\eta_{KL}(R)$ is given by Scofield [23]

$$\eta_{KL}(R) = \omega_K \left[\frac{I(KL_i)}{I_K(R)}\right] \tag{2}$$

and the nonradiative vacancy transfer probability, $\eta_{KL}(A)$ is given by Bambynek et al. [5]

$$\eta_{KL}(A) = (1-\omega_K)\left[b_i + \frac{I(K-L_iX)}{I(K-LL)}\right] \times \left[1 + \frac{I(K-LX)}{I(K-LL)} + \frac{I(K-XY)}{I(K-LL)}\right]^{-1} \tag{3}$$

Here b_i denotes the probability per K–LL transitions of producing a L_i vacancy.

The total vacancy transfer probability, η_{KL} can be expressed in terms of K shell fluorescence yield, ω_K and K X-ray intensity ratio $IK\beta/IK\alpha$ as given by Schonfeld and Janben [7] as

$$\eta_{KL} = \frac{2-\omega_K}{1+\dfrac{IK\beta}{IK\alpha}} \tag{4}$$

Therefore, by knowing the K shell fluorescence yield and the K X-ray intensity ratio, the total vacancy transfer probability η_{KL} from K to L can be determined.

The K shell fluorescence yield, ω_K is defined as the number of the K X-ray photons emitted per vacancy created in the K shell.

$$\omega_K = \frac{I_K}{n_K} \tag{5}$$

where I_K is the number of K X-ray photons and n_K is the number of K shell vacancy created in the target. The quantity $n_K = I_0 n_a \tau_K$, where I_0 is the number of photons incident on the target, n_a is the number of the target atom per cm^2 of the target and τ_K is the K shell photoelectric cross section taken from Scofield [14]. The quantity $n_a = N_0 t/A$, where N_0 is the Avagadro's number, t is the mass per unit area of the target in terms of g/cm^2 and A is the mass number of the target. Therefore, by measuring the K X-ray intensity I_K and the incident intensity I_0, the K shell fluorescence yield, ω_K can be determined.

Similarly K X-ray intensity ratio $IK\beta/IK\alpha$ can be determined by knowing the area under $K\beta$ and $K\alpha$ X-ray peaks. The K X-ray intensity ratio is given by

$$\frac{IK\beta}{IK\alpha} = \frac{N_{K\alpha}\varepsilon_{K\beta}\beta_{K\beta}}{N_{K\beta}\varepsilon_{K\alpha}\beta_{K\alpha}} \tag{6}$$

where $N_{K\alpha}$ and $N_{K\beta}$ are the total number of $K\alpha$ and $K\beta$ X-ray photons respectively. The $\varepsilon_{K\alpha}$ and $\varepsilon_{K\beta}$ are efficiencies of the detector for $K\alpha$ and $K\beta$ X-ray photons. The $\beta_{K\alpha}$ and $\beta_{K\beta}$ are the self attenuation factors for $K\alpha$ and $K\beta$ X-ray photons, respectively.

We have adopted a 2π geometrical configuration using a weak ^{57}Co source and measured I_0, I_K and $IK\beta/IK\alpha$ for