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Study of L_γ X-Ray Emission from α Decay of ^{210}Po

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L_γ x-ray emission from α decay of ^{210}Po has been studied as a first step for the alignment experiment of the L subshell vacancy. The observed L_γ x-ray spectrum has been decomposed into the six transition lines of $L_{\gamma5}$, $L_{\gamma1}$, $L_{\gamma2}$ and $L_{\gamma3}$ (L-N transition), and $L_{\gamma6}$ and $L_{\gamma4,4'}$ (L-O transition). No energy shift has been found within an accuracy of ± 10 eV for all the transition lines observed and the measured relative intensity ratios are in agreement with Scofield values within $\pm 10\%$. It is concluded that, when an L x ray is emitted, no spectator vacancy is present in M shell and the number of N vacancies can be estimated to be less than one. Since the presence of spectator vacancy may have a possibility of destroying the alignment, the obtained result indicates that greater alignment can be expected in α decay when compared with ion-atom collision. An overview of the electronic transition during α decay is also given in the introductory part of this work.

KEY WORDS: L_γ x rays/ α decay/ ^{210}Po/ Energy shift/ Multiple vacancy/ Alignment of L shell/

I. INTRODUCTION

There are numerous experimental and theoretical investigations on the electronic excitation and ionization of an atom induced by charged-particle impact[1]. These investigations cover a wide field of the ion-atom collision phenomena, such as charge-state distribution, inner-shell ionization and multiple ionization of a target atom bombarded by accelerated ions of many kinds, from proton to uranium. It is surprising, however, that despite the progress made in the atomic collision, the study of electronic transition due to nuclear α decay is still in an unsatisfactory state. Since α decay can be considered to be a part of the collision process of α+daughter atom with only an out-going part and an impact parameter $b=0$, we believe that α decay, as a whole atomic decay, is providing very pure and clear-cut situation for the study of the electronic transition under the influence of the Coulomb interaction of charged particle. From this viewpoint on nuclear α decay, we have made a series of measurements by utilizing ^{210}Po which is unique and most suitable nuclide in studying electronic transition, as explained in Ref. 2.

In order to study *outer-shell ionization*, charge-state distribution of daughter atom, ^{206}Pb, was measured in the work of Ref. 2 and theoretical interpretation was made in Ref. 3. From these works, we concluded as follows: (1) The α-decay influence on the electronic structure can be divided into two parts; the adiabatic part for the inner-shell electrons and the sudden part for the outer-shell electrons, because the velocity of α particle is 7.3 v_b, where v_b is the Bohr velocity of $e^2/\hbar$, and thus it is much slower than the orbital-electron velocities of the three innermost shells, but much faster than those of the

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two outermost shells. Therefore, the energy responsible for outer-shell ionization is considered to originate from the rearrangement energy deposited on the outer-shell electrons through the sudden change of the nuclear charge, while the contribution from the adiabatic part is negligibly small in comparison with that from the sudden part. (2) The evaporation model[4] developed by Russek and collaborators for multiple ionization of outer-shell electrons in ion-atom collisions can be applied for the charge distribution. This model takes into account that the outer-shell ionization is caused by the statistical nature of collective motion of outermost electrons influenced by α-particle perturbation.

In order to extend our work to the *inner-shell ionization* in α decay, we have been measuring L x rays emitted following L-shell vacancy creation during α-particle passage through atomic-electron cloud. The probability of L-shell ionization is reported to be as small as $\sim 8\times10^{-4}$ per α decay[5]. It should be emphasized that the adiabatic part mentioned above is responsible for the ionization, which is contrary to the case of outer-shell ionization. In this L x-ray measurement, our aim is two fold: (1) To study the formation of M- and N-shell vacancies being present when an L x ray is emitted. We do this through L_γ x-ray measurement. L_γ x ray, among L x lines of L_l, L_α, L_β and L_γ lines, is particularly sensitive to the degree of multiple ionization in M and N shells. This was clearly demonstrated for the first time in our previous works[6] employing accelerated heavy ions of 10- and 20-MeV oxygen and 88-MeV neon. (2) To understand detailed inner-shell ionization mechanism, including the mechanism in ion-atom collision, through the alignment of L-subshell vacancy. As pointed out by Kabachnik[7], one may expect that the alignment in α decay would be greater than that in ionization by particle impact, since the dependence on the impact parameter b is of alternating sign, so averaging over b, which is the case in the particle impact, decreases the alignment. Thus, we can take full advantage of the clear-cut situation of α decay, i.e., only an out-going part and $b=0$. In short, the alignment phenomena can be used as a very sensitive tool to examine the detailed ionization mechanism.

Although we have set our final goal in measuring the alignment of L-subshell vacancy created in α decay by taking coincidence between α's and L x rays, the presence of additional vacancies may have a possibility of destroying the alignment. Therefore, as a first step to the alignment experiment, we have made a single measurement of L_γ x rays to examine the presence of spectator vacancies in M and N shells. Here, reported is the result of analysis of L_γ x rays emitted from α decay of ^{210}Po.

II. EXPERIMENTAL

The ^{210}Po source was prepared by electrodeposition on an aluminum foil. The solution of $Po(NO_3)$ in 5 ml 3 N HNO_3 purchased from Amersham International plc, England, was purified by a solvent-extraction method, the details of which is described in Ref. 2. In order to achieve electrodeposition onto aluminum, we followed Puphal and Olsen[8] who developed an electrodeposition method utilizing an ammonium chloride-ammonium oxalate electrolyte. The source prepared in this manner had an activity of $\sim$37 μCi and an active area of $\sim$3 mm diameter. X rays emitted from the source were measured with an Ortec Si(Li) detector (28 mm$^2\times$5.2 mm^t) with a resolution of 190 eV (FWHM at 5.9 keV). The source was mounted 1 cm apart from the detector, in front of which Mylar films of a total thickness of 150 μm were placed to absorb M x rays from the source. Owing to the low counting rate of $\sim$3 counts/s for the total energy region studied (3–57 keV), the measurement was made for the period of 4.97×10^5 sec. The electronics used was found to be stable during the measurement.

III. RESULTS AND DISCUSSION

In previous work[6], we succeeded in decomposing the L_γ x-ray spectrum, which was perturbed due to multiple vacancies, into the six transition lines of $L_{\gamma5}$, $L_{\gamma1}$, $L_{\gamma2}$ and $L_{\gamma3}$ (L-N transition), and $L_{\gamma6}$ and $L_{\gamma4,4'}$ (L-O transition). In the same fashion, the least-squares fitting analysis has been made by using a computer code (ISOFIT), in which the constraints that $\Delta E_5 = \Delta E_1 = \Delta E_2 = \Delta E_3$ and $\Delta E_6 = \Delta E_{4,4'}$, where ΔE_i is the upward energy shift of the $L_{\gamma i}$ line, respectively, are set and linear background is used. Figure 1 shows the observed L_γ x-ray spectrum, together with the decomposed six transition lines. The excellent fit to the spectrum has disclosed how the $L_{\gamma2}$, $L_{\gamma6}$ and $L_{\gamma3}$ lines lie in the region where the lines cannot be resolved using a Si(Li) detector. The fitting analysis has revealed as follows: (1) The peak shapes can be well represented by the Gaussian functions. Their half widths are found to be equal for all the lines, even for the $L_{\gamma4,4'}$ line. (2) The measured relative intensity ratios of $L_{\gamma2}/L_{\gamma3}/L_{\gamma4,4'}$ (L_{I} transition) and $L_{\gamma5}/L_{\gamma6}/L_{\gamma1}$ (L_{II} transition) are in agreement with the Scofield values[9] within $\pm 10\%$. (3) The energy shift has not been found for any of the lines within ± 10 eV.

Since the energy shift is mainly caused by the spectator vacancies being present *in-*

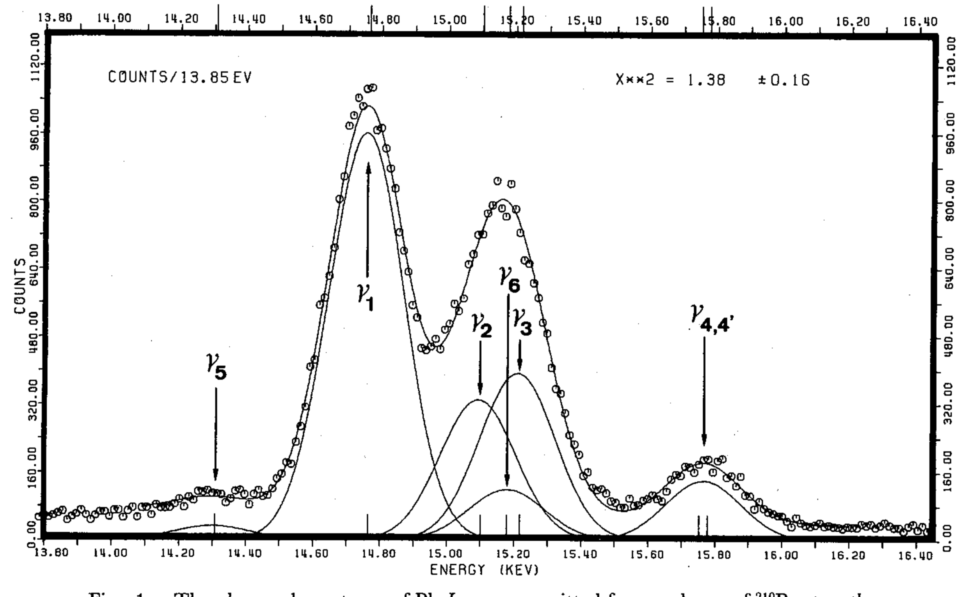

Fig. 1. The observed spectrum of Pb L_γ x-rays emitted from α decay of ^{210}Po, together with the result of the least-squares fitting analysis that has decomposed the spectrum into the six transition lines of $L_{\gamma5}$, $L_{\gamma1}$, $L_{\gamma2}$, $L_{\gamma6}$, $L_{\gamma3}$ and $L_{\gamma4,4'}$ lines. The energy dispersion is 13.85 eV/channel.

side the transition involved, the energy shift for the L-O transition can be interpreted as the sum of the shifts due to M and N vacancies, thus providing the most sensitive tool for examining the presence of these vacancies. As is shown in the previous work[6], the change in the relative intensity ratio and the broadening of the $L_{\gamma 4, 4'}$ line are also good indications of the presence of the vacancies. Uchai *et al.*[10] calculated the average energy shift per M vacancy for the $L_{\gamma 4, 4'}$ line to be 92 eV in the case of Pb. The corresponding shift per N vacancy has not yet been reported, except for our calculation[11] that has been made only for Bi by using the Dirac-Fock computer program of Desclaux[12]. We have found the shift of 15 eV per N vacancy for the $L_{\gamma 4, 4'}$ line of Bi. The value of the shift for Pb should be slightly smaller than that for Bi. Thus, our findings from the fitting analysis lead us to the conclusion that, when an L_γ x ray is emitted, no M-shell spectator vacancy is present and the number of N-shell vacancies can be estimated to be less than one. We can say that the L-shell ionization in nuclear α decay provides an ideal situation for the alignment experiment of the L-subshell vacancy, since the additional vacancies, if exist, may destroy the alignment.

Finally, we would like to point out that the high-resolution measurement of the L_γ x-ray lines, especially of the $L_{\gamma 4, 4'}$ line, with a crystal spectrometer, is highly hoped since the detailed structure of the lines could reveal the nature of the multiple vacancies in outer shells, where there may be a complicated rearrangement of the vacancies prior to the L x-ray emission owing to the solid-state effect.

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