INSTITUTE FOR NUCLEAR STUDY
UNIVERSITY OF TOKYO
Tanashi, Tokyo 188
Japan

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M. Sakai, Y. Fujita, M. Imamura,
K. Omata, S. Ohya and T. Miura

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M. Sakai, Y. Fujita, M. Imamura and K. Omata
Institute for Nuclear Study, University of Tokyo
Tananshi-shi, 188 Tokyo, Japan

S. Ohya
Niigata University
Niigata, Japan

T. Miura
National High Energy Laboratory
Tsukuba, Japan

Abstract

The thorium target was irradiated by positrons from a ^{118}Te-^{118}Sb beta-plus source and electrons emitted from the target were measured by means of an electron spectrometer and a counter telescope consisting of two position sensitive counters. We have observed excess electrons located at 328.6±0.3 keV in the spectrogram. The kinematic energy and the intrinsic FWHM of the electron line were deduced to be 333±1 keV and 3.7±0.3 keV, respectively and the cross section was estimated as 120±40mb.

If we assume that the electrons result from the decay of an anomalous particle emitting an electron-positron pair with the same energy, its mass is to be 1688±2 keV.

1. INTRODUCTION

One of the most popular topics of the recent nuclear physics is that of the light pseudoscalar Goldstone boson, the axion.[1-2)]

People at GSI have observed a sharp positron peak at about 330 keV appearing in supercritical heavy-ion collisions.$^{3-4)}$ Later electron-positron coincidence experiments were carried out and correlated narrow peak structures in positron and electron spectra were also obtained.$^{5)}$ This peculiar phenomenon has been interpreted in terms of the production and subsequent decay of a neutral pseudoscalar particle, that is, "axion".$^{6-7)}$ Recently coincidence positron and electron peaks of 340±10 keV in e^+ + Th interactions were reported.$^{8)}$ As their energy is almost the same as that of positron peak observed in heavy ion collisions, the authors have considered this newly discovered peak as associated with the axion.

The experiment consists of bombardment of positrons from the decay chains of ^{68}Ge($T_{1/2}$=288d; Q_{EC}=0.114 MeV; EC=100%) $\rightarrow$ ^{68}Ga($T_{1/2}$=68.1m; Q_{EC}=2.921 MeV; EC=10%; β^+=90%) $\rightarrow$ ^{68}Zn on a thorium metallic foil of 40 - 60 mg/cm^2 thickness covered on the source and of coincidence measurements of electrons and positrons emitted from the irradiated target with two mini-orange spectrometers.

If we assume that an unknown particle produced in the target decays by emitting an electron-positron pair with the same energy, its mass is to be 340±10 x 2 + 2 mc^2 = 1702±20 keV. As the endpoint energy of the spectrum of ^{68}Ga is Q_{EC} - 2 mc^2 = 1899 keV, the positron intensity above the 1702-keV threshold energy is only 0.7% of the total intensity. This small portion of the spectrum available for the production of the relevent particle may be the main cause to make the peak in question very tiny on the huge coincidence positron spectrum taken with electron energy bin of 340±10 keV (see fig. 3 of ref. 8). Also the target thickness of 40 - 60 mg/cm^2 caused to shift the energy of emitted electrons or positrons by about 30 keV and to broaden the peak. In consequence it introduced considerable uncertainty for determination of peak energy. For example, the energy of a peak observed on the coincidence positron spectrum was 345 keV while that of electron peak 335 keV. Also we can not estimate the intrinsic width of the original line, due to the large breadth of the peak. All these experimental conditions described above make it difficult to deduce the production cross section with certain accuracy.

In view to confirm this interesting phenomenon, that is, the production of anomalous particles in e^+ + Th interactions, we carried out an experiment by means of an air-core magnetic spectrometer together with a counter telescope specially designed for detection of weak lines. We used the decay chains of ^{118}Te($T_{1/2}$=6.00 d; Q_{EC}=0.296 MeV; EC=100%) $\rightarrow$ ^{118}Sb($T_{1/2}$=3.5 m; Q_{EC}=3.686 MeV; EC=22.5%; β^+_{gr}=75%, β^+_{ex}=2.5%) $\rightarrow$ ^{118}Sn as a beta plus emmitter. The endpoint energy of the positron spectrum of the source being 2664.3 keV, the positron intensity above the threshold energy of 1702 keV is 19% of the total intensity in contrast with 0.7% for the ^{68}Ge-^{68}Ga source. We used a thin collodion film containing thorium of 3.0 mg/cm^2 as a target. It causes the energy loss of about 5 keV. Such experimental conditions could be expected to study the phenomenon in a much more straightforward way than in the reported case.

2. EXPERIMENTAL PROCEDURES

The parent radioisotope of ^{118}Te was produced via ^{116}Sn(α,2n)^{118}Te reactions by bombarding 40-MeV α particles from the INS Cyclotron on enriched ^{116}Sn target and radiochemically separated by ion exchange method. The separated radioactivities were chemically adsorbed as AgTe on a sheet of 10μm thick silver foil within an area 2mm x 20mm. The thorium target was made by spreading diluted collodion solution suspended with fine thorium metallic powder on a glass plate. Total thickness was 5 mg/cm^2 of which the thorium composition was 3 mg/cm^2. The collodion film containing thorium powder was cut to 5mm x 24mm in size and covered over the source. The target-source system was placed at the source position in the INS air-core double focusing electron spectrometer with ρ= 75cm.9)

The counter telescope was composed of two position sensitive single wire proportional counters of 30cm length.10) The coincidence system reduces background four times in comparison with the case of the singles mode. The spectrum was taken spectrographically with baffle setting for $\Delta p/p$=1% and Ω=1.2%/4π and displayed over 1500 channels with a momentum range of 8%. It enables to accumulate a large amount of counts. The low background and the large accumulated counts of spectrographically taken spectra are specific features of the present experiment for detecting weak electron lines.

3. EXPERIMENTAL RESULTS

The magnetic field was adjusted to focus 340-keV electrons on the center of the spectrogram. Fig. 1 is the spectrum with measuring period of 3944 min. Large amount of electrons could be explained by struck electrons due to Bhabha scattering and Compton electrons produced by gamma rays and annihilation radiations. The low counting rates at the high and the low energy side of the spectrogram can be accounted for by the low relative efficiency of electron detection. Any visible sign of peak does not appear in the spectrogram.

Second, we took out the target film and measured positrons by inversion of the magnetic field. The positron spectrum with measuring period of 180 min is shown in fig. 2. Assuming the smoothness of the curves of figs. 1 and 2, we divided electron counts summed over 50 channels by corresponding positron sum counts. The ratios are plotted in fig. 3. It turned out that the plots take a smooth curve to prove the validity of the assumption made above. Moreover, we can notice a bump in a region between 500 and 650 channels. Excess electrons corresponding to the bump were calculated with the following formula:

$$n_{e^-} = N_{e^-} - R_o N_{e^+} \quad ,$$

where N_{e^-} and N_{e^+} are electron and positron sum counts, respectively, and R_o is the ratio estimated by interpolating the smooth parts of the curve outside of the relevant region as indicated in the figure. The curve of n_{e^-} shows a symmetric shape as presented in the same figure. The energy, the FWHM width and total counts of the excess electrons are 328.6±0.3 keV, 3.7±0.3 keV and 3000±500, respectively. The energy loss of 329-keV electrons was calculated by the Landau formula$^{11)}$, where we assumed electrons to pass through the target film. We found the average energy loss of 4.7 keV. The electron-path in the target must be shorter than the full thickness of the target, because the detected electrons might be born in the target. Therefore, the figure given above can be considered as the upper limit for the energy loss. Then, the corrected value for the peak energy is 333±1 keV which is fairly consistent with that in ref. 8 and in agreement with the value of 336±10 keV observed at GSI.[3)] The width was found to correspond to the instrumental resolution so that the intrinsic width must be smaller than this value. The electron intensity was deduced by taking into account the position and energy dependences of counting efficiency and found to be 4700±830. The errors result mainly from the uncertainty of the estimation of R_0 and energy dependence.

4. DISCUSSIONS

First, we discuss various possibilities which may cause a peak structure with the present experimental conditions. Struck Bahbha electrons have no reason to give a peak structure by their physical nature. Internal conversion electrons emitting from the source and passing through the target may give a peak. We checked gamma transitions in the decays of ^{118}Te and ^{119}Te which give conversion lines in the energy range of the spectrogram. The ^{119}Te was found in the source which was produced by the (α,n) reactions. No gamma rays satisfying the above condition were found except the 369.75-keV transition in ^{119}Sb of which the K line is expected to be observed at 334.8 keV because of the energy loss. However, the energy is different by 6 keV from that of the observed peak so that the possibility of interpreting the present peak as the K internal conversion peak of the 369.75-keV transition may be excluded. Also we could not see any sign at the right position as indicated by arrow in fig. 3. It may be due to the very small intensity (0.03% per decay) of the relevant transition.[12)] A possibility of external conversion electron peaks resulted from the interaction of gamma rays of the source with thorium nuclei in the target was also examined. After having checked carefully, we excluded such a possibility. Finally we considered the effect of Compton electrons caused by annihilation gamma rays. As the radiations occur uniformly in the source or in the target, electrons emitting perpendicularly to the target surface and arriving at the counter are to be produced by the radiations with scattering angles between 0° and 90° . Therefore, though the Compton edge of the 511-keV radiation is 340.7 keV, the production mechanism described above makes the Compton bump very wide to the extent that we could not imagine to have a peak with FWHM less than 1% observed in the present experiment.

After these examinations of the various possibilities discussed above, we have arrived at the conclusion that the peak is in effect the genuine one resulting from the interactions of positrons with thorium nuclei and might have the same origin as that observed previously by the different method. We assumed that anomalous particles are created by positrons above the threshold energy with energy independent cross section and decay by emitting isotropically 333-keV electrons with partener positrons of the same energy at opposite direction. With these assumptions the cross section was calculated by using the positron intensity above the threshold energy estimated by source activity and branching percentage of the ground state transition, target thickness, observed electron intensity and the measuring period. It was to be 120±40 mb. The errors came mainly from the estimation of the effective thickness of the target averaged by the positron pass length in the target and of the observed electron intensity discussed in the preceding section. The magnitude of the cross section is fairly larger than that in ref. 8. As to the energy width of the electrons, we can say only less than 3.7 keV because the width results mainly from the resolution of the spectrometer.

5. CONCLUSION

We observed the peak with a precision much higher than the previous work. The energy, the width and the cross section are 333±1 keV, 3.7±0.3 keV and 120±40 mb, respectively. The mass of the particle is to be 1688±2 keV.

The next step of our experiment is to study the Z dependence of peak energy and cross section by changing target materials, like tantalum, bismuth and uranium. Also it is of interest to investigate the energy dependence by using various sources which have the different endpoint energy. Finally we must check the presence of monochromatic positrons produced in the interactions between positrons and nuclei by using some kind of coincidence apparatus.

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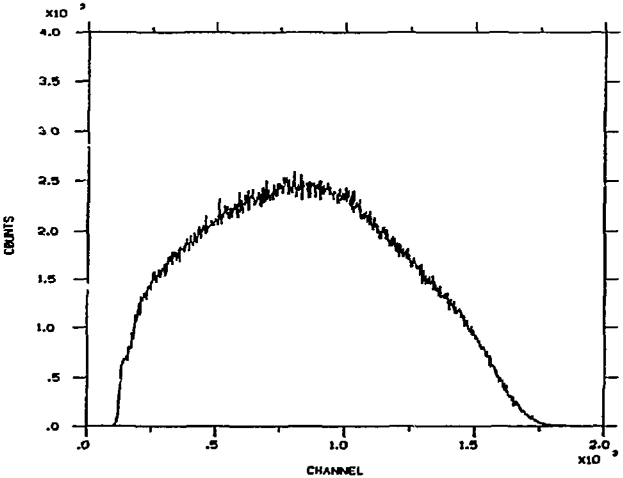

Fig. 1 Electron spectrogram from positron bombardment of a thorium target. The measuring period is 3944 min.

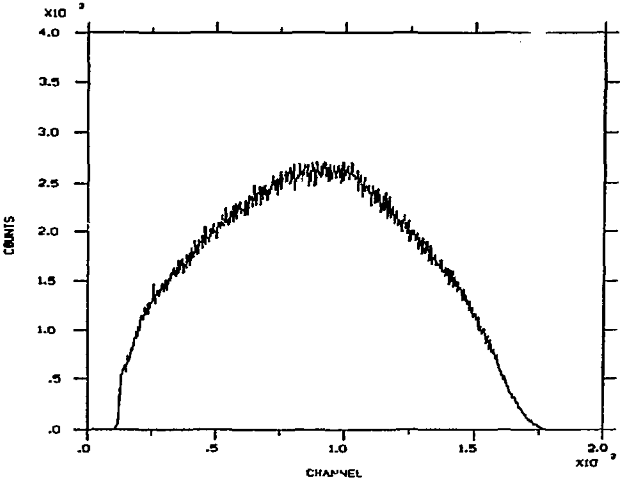

Fig. 2 Positron spectrogram taken with a bare positron source by inversion of the magnetic field. The measuring period is 180 min.

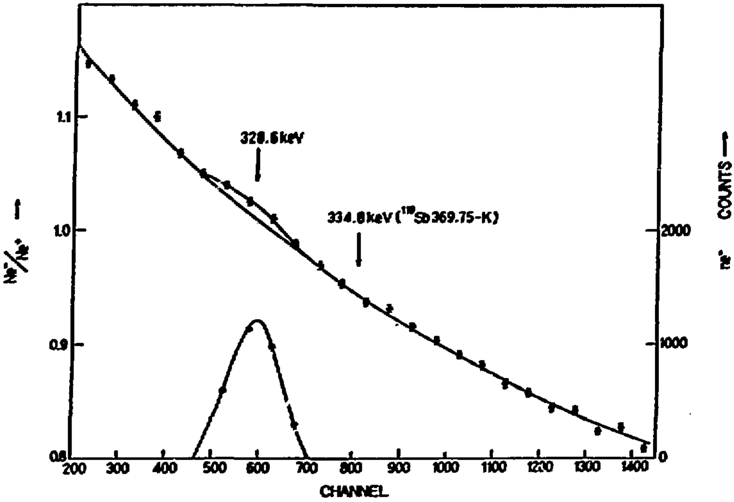

Fig. 3 Ratios of N_{e^-}/N_{e^+}. Counts are summed over 50 channels. Excess electrons estimated by interpolating the curve outside of the relevant region (see text) are shown with the scale of right-hand ordinate. The position corrected by energy loss for the 369.75-K line of ^{119}Sb is indicated.