Measurement of Change of ^{7}Be Decay Rate in Be and Au

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We have measured the possible change of the decay rate of ^{7}Be implanted into hosts of natural beryllium and natural gold. No difference between the ^{7}Be decay rates in the two hosts is observed within the experimental precision of 0.12%. This result implies that change of the decay rate of ^{7}Be implanted in different materials cannot be simply expected from the electron affinity difference consideration lonely and the lattice structure of the host materials should be taken into account.

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Electron-capture decay rates depend sensitively on the density of atomic electrons within the nucleus. Thus, physically and chemically environmental factors such as pressure, chemical form, magnetic fields, etc., which can change electron densities, may affect electron-capture decay rates. Since the change of nuclear decay in different environments has fundamental significance, as well as application in nuclear physics, astrophysics, geology and condensed matter physics, such a study is of current interests.[1−5] Furthermore, ^{7}Be is the lightest radioactive nucleus that decays by electron capture with a half-life of ~ 53 days, thereby, it is a good candidate for studying perturbation of nuclear decay rates. Furthermore, the study of decay rate changes for ^{7}Be has particular significance to the solar neutrino problem, where there is a large discrepancy between theoretical predictions and experimental determinations of the solar neutrino flux.[3,6−8]

The ^{7}Be decay rate sensitively depends on chemical environments at the nucleus. Changes of decay rates of ^{7}Be nuclei in different ^{7}Be compounds have been measured at normal pressure and a maximum change is about 1.5%.[9] Moreover, this decay rate is also sensitive to physical environments, such as high pressure and host materials in which the ^{7}Be nucleus is located. Liu and Huh have measured a large increase, up to 1%, of the decay rate of ^{7}Be under a high pressure of 400 kilobars.[10] Recently Norman *et al.* measured the decay rate of ^{7}Be implanted into hosts of lithium fluoride, gold, graphite, boron nitride, tantalum, lithium, and so on. It has been found that the ^{7}Be decay rate varies by as much as 0.72% from one host to another.[11−14] Qualitatively, it has been reported that if a ^{7}Be atom is implanted in a medium having high electron affinity (EA), as a result of its interaction with nearby atoms of such a medium, the ^{7}Be atom would lose a significant fraction of its 2s electrons.[12] The decay rate of ^{7}Be in a high-EA medium is thereby smaller than that in a low-EA medium. Thus, we would expect that ^{7}Be implanted in natural gold ($\mathrm{EA_{Au}} = 2.308\,\mathrm{eV}$[15]) should decay slower up to 0.7% than that in natural beryllium ($\mathrm{EA_{Be}} = -0.19\,\mathrm{eV}$[15]) according to the result of Ray *et al.*, in which difference up to 0.72% between the decay rates of ^{7}Be implanted in Au and in Al_2O_3 was observed.[12]

In this Letter, we report our measurement of possible change of the decay rate of ^{7}Be implanted into metal foils of natural beryllium and natural gold. The ^{7}Be nuclei are produced by bombarding a $500\,\mu\mathrm{g/cm^2}$-thick foil of lithium fluoride (LiF) with a 3.2 MeV proton beam, with average current $5\,\mu$A, from the 5 SDH-2 tandem accelerator at CNNC Radiation Metrology and Measurement Center, China Institute of Atomic Energy. Thus, ^{7}Be nuclei produced by the reaction ^{7}Li (p,n) ^{7}Be with recoil energy 1.0 MeV in the forward direction are implanted into beryllium and gold foils placed immediately behind the LiF target. The implantation for each foil lasts about 15 h. As a result of such implantations, ^{7}Be atoms are expected to be randomly located in the interstitial lattice space of the host media beryllium and gold.

By electron capture the nucleus ^{7}Be decays to the $3/2^-$ ground state of ^{7}Li directly with a branching ratio of 89.5% and to the first excited state with a ratio of 10.5%, which decays subsequently to its ground state by emitting 478-keV gamma rays.[16] In this experiment, two high-purity coaxial germanium (HP Ge) detectors are used to measure the 478-keV gamma-ray photons. The ^{7}Be implanted beryllium and gold foils are separately mounted about 2 cm away from the endcups of two HP Ge detectors. The two detectors, each is surrounded by a graded shield of organic glass-Al-Cu-Pb, are located at 4 m away from each other to

avoid cross detection of the gamma-ray photons from the two sources. The gamma-ray spectra are accumulated with a KODAQ data acquisition system.

In order to decrease as much effect originated from the decays of short-lived isotopes produced in bombarding as possible, we wait for about 40 d to start to acquire experimental data. The two gamma-ray spectra are acquired for successive one-hour intervals and recorded on a computer hard disc. Then this is followed by next interval automatically. After such a measurement has lasted about 70 d, we exchange the positions of the two sources, while keeping other measurement conditions unchanged, and we measure for another 50 d. We extract from each time bin the net peak area of the 478 keV ^{7}Be gamma-ray and its time information after dead-time correction and time calibrations with the time provided by the Hong Kong observatory. Figure 1 shows a typical gamma-ray spectrum in a one-hour counting period from the gold sample. The ratio method, as to be described below, is employed to draw the possible difference in the decay rate of ^{7}Be nuclei implanted in beryllium and gold. Let $A_{\rm Be}$ and $A_{\rm Au}$ denote the numbers of 478 keV gamma-ray photons measured by the corresponding detectors within an interval of t to $(t+1)$ days. Similarly, let $A^0_{\rm Be}$ and $A^0_{\rm Au}$ denote the numbers of 478 keV gamma-ray photons measured by the corresponding detectors within an interval of 0 to $t=1$ days. Let $\lambda_{\rm Be}$ and $\lambda_{\rm Au}$ denote the decay rate of the ^{7}Be nuclei in the beryllium and gold samples respectively and let $\lambda_{\rm Be} = \lambda_{\rm Au} + \Delta\lambda$. Then

$$\ln R(t) = \ln R_0 - \Delta\lambda t, \qquad (1)$$

where

$$R(t) = \frac{A_{\rm Be}}{A_{\rm Au}}, \quad R_0 = \frac{A^0_{\rm Be}}{A^0_{\rm Au}},$$

and $\Delta\lambda$ is the difference in the decay rate.

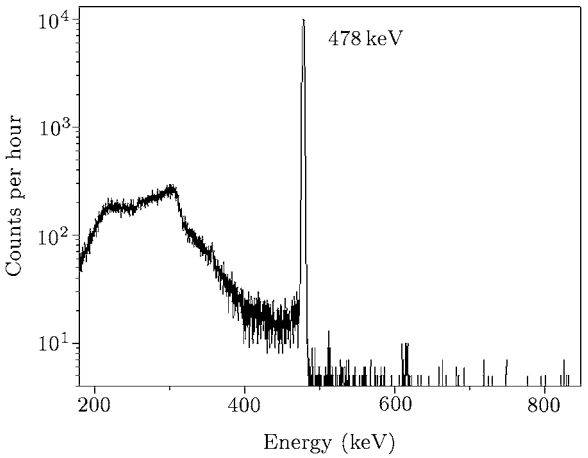

Fig. 1. A typical gamma-ray spectrum obtained in one-hour counting interval from ^{7}Be in the gold sample.

Figures 2(a) and 2(b) show the experimental data of $\ln R(t)$ versus t and corresponding linear fit lines before and after exchanging the source positions, respectively. The $\Delta\lambda$ value is determined by the slope in each case. The value of $\Delta\lambda$ derived from Figs. 2(a) and 2(b) are $0.3\times10^{-5}\pm0.8\times10^{-5}$ and $0.7\times10^{-5}\pm1.5\times10^{-5}$, respectively. By fitting the exponential decrease of $A_{\rm Au}$ versus time t for the two cases, we obtain the weighted value 0.012985 ± 0.000004 for the decay rate of ^{7}Be implanted in gold and 0.012986 ± 0.000004 in beryllium. Then using λ equal to 0.012986, we obtain the values of $\Delta\lambda/\lambda = (0.02\pm0.06)\%$ before the source exchange and $\Delta\lambda/\lambda = (-0.05\pm0.12)\%$ after the source exchange. This result indicates that within our experimental precision, the large change in the decay rate of ^{7}Be in Be and Au is not observed and an upper limit 0.12% of this change can be set.

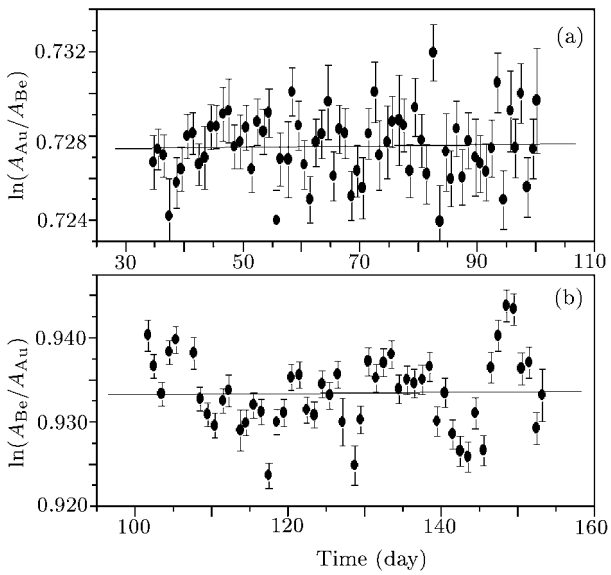

Fig. 2. Characteristics of $\ln R(t)$ versus time (a) before and (b) after exchanging sources positions. The solid lines are the linear fit of the experimental data.

In conclusion, we have performed the first-ever measurement of the possible change in the decay rate of ^{7}Be implanted in natural beryllium and natural gold. According to the large difference of electron affinity between beryllium and gold, a large change of 0.7% in the decay rate of ^{7}Be in the two cases is expected. However, within our measurement precision ($\sim\pm0.06$ and 0.12% for the measurement before and after the source exchange respectively) no difference between the decay rates of ^{7}Be implanted in beryllium and in gold is observed. This result implies that except electron affinity the lattice structure of the host medium in which the ^{7}Be atom sits has to be taken into account.

Our experimental result also indicates that the difference between the average electron numbers in L-shell ($2s$ state) of ^{7}Be atoms in the two samples is smaller than our measurement precision of $\sim 0.1\%$, since the K-shell capture rate should essentially remain unchanged in different environments. According to the calculation of Ray *et al.*, which has taken the lattice structure into account, the average number of $2s$ electrons of ^{7}Be atoms implanted in natural beryllium sample should be equal to 0.443 while that in the gold sample should be 0.416.[12,17,18] Thus, from Hartree's calculation that the ratio of the square of the beryllium $2s$ electronic state wavefunction ($2s$ electrons) to that of $1\,s$ state wavefunction at the nucleus ($r = 0$) is 3.31%,[19] the decay rate of ^{7}Be in natural beryllium should be faster than that in gold by 0.045%. However, this value is beyond the reach of our measurement precision.

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