Half-life Measurement of 7Be in Different Chemical and Physical Environments

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VI. 1. Half-life Measurement of ^{7}Be in Different Chemical and Physical Environments

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The constancy of nuclear half-life has been firmly established experimentally as an exponential decay law. However, in one of β-decay modes, electron-capture (EC) decay rate depends on the density of atomic electrons within the nucleus as first suggested by Segr'e et al[1]. The general understanding is that the wave function of the initial and final states between atomic electrons and the nucleus, respectively, should be considered in the EC decay. Therefore, external factors such as chemical form, metal host, pressure, and even temperature may alter the densities of the electron overlap with the nucleus, and thus, affect the EC decay rates. A long-standing debate exists regarding to what degree nuclear decay rates can be changed artificially. The EC decay nucleus ^{7}Be has been used to look for effects of external-electron density on decay half-lives, because of its simple electronic structure ($1s^2 2s^2$) in neutral Be atom and its adequate half-life for measurement. So far, the success of the ^{7}Be endohedral C_{60} ($^{7}Be@C_{60}$) and ^{7}Be in Be metal [Be metal (^{7}Be)] has allowed us to measure the half-life of ^{7}Be. Then, we have measured the half-life of ^{7}Be in the sample of $^{7}Be@C_{60}$ and Be metal (^{7}Be) by using a reference method and standard clock time. It was revealed that the half-life of ^{7}Be inside C_{60} was almost 1 % shorter than that in Be metal in room temperature. This fact implied that the ^{7}Be atoms are located in a unique environment inside C_{60}[2].

Several factors contribute to this environment: the many π electrons and dynamic motion etc. inside fullerenes (at room temperature). Therefore, it is intriguing to study the temperature and the cage (C_{60}, C_{70}) dependence of the half-life of ^{7}Be inside C_{60} (and C_{70}). In the present study, in order to look for the effects of the dynamic motion of ^{7}Be inside C_{60} (C_{70}), we measure the half-life of ^{7}Be in the sample of $^{7}Be@C_{60}$ and $^{7}Be@C_{70}$ that had been cooled to a temperature close to liquid helium (T=5K).

One way to produce atom endohedral C_{60} (C_{70}) is to insert foreign atoms into preexisting C_{60} (C_{70}). We produced an endohedral C_{60} (C_{70}) by nuclear recoil implantation[3,4]. Recently, we developed a reference method to measure the half-life of ^{7}Be inside C_{60} (C_{70}) and that in Be metal. The method used to produce the ^{7}Be@C_{60} (C_{70}) and ^{7}Be reference samples (Be metal (^{7}Be) has been described elsewhere[2]. In order to measure the half-life at T=5K, the ^{7}Be@C_{60} (C_{70}) sample was placed in the top of a He closed-cycle cryostat. The two samples, ^{7}Be@C_{60} (C_{70}) (fastened in the cryostat) and Be metal (^{7}Be), were placed in a computer-controlled sample changer, which moved the samples precisely in front of a γ-ray detector. The measurement was started after the ^{7}Be@C_{60} (C_{70}) sample underwent sufficient cooling at T=5K in the vacuum state. This arrangement allowed the decay rates of the two samples to be measured in a consistent fashion while reducing systematic errors. In the system, the internal clock time of the computer for data acquisition was constantly calibrated by a time-standard signal distributed via a long-wave radio center in Japan. The 478 keV γ-rays emanating from the EC-decay daughter (the first excited state of ^{7}Li) of ^{7}Be were measured using a HPGe detector coupled to a 4096-channel pulse-height analyzer. Here, we set the specific measurement duration to 21600 seconds (21480 seconds for the live measurement time and 120 seconds for the dead-time of the measurement system plus the sample exchange) for one data point. The amount of radioactivity associated with the decay of ^{7}Be (E_{γ}=478 keV) could be uniquely analyzed through the identification of characteristic γ-rays. The decay curves obtained in the present measurements were fitted, by use of the MINUIT program distributed by the CERN Program Library. The uncertainty of our measurement corresponds to that of the slope of the straight line fitted to the logarithm of the counts (i.e., counts per second) of the decay curve. The reduced chi-square values of the exponential fits are between 0.9 and 1.1. The uncertainty due to the dead time was estimated to be less than 0.04%, and the systematic error in the measurements was estimated to be less than half of the statistical errors.

We have measured the decay rates and deduced the corresponding half-lives of ^{7}Be in samples of ^{7}Be@C_{60} at T=5K and 293K, ^{7}Be@C_{70} at T=293K and in Be metal(^{7}Be) at T=293K with durations of almost three half-lives of ^{7}Be. In Fig. 5, the open circles indicate the half-lives obtained for the ^{7}Be@C_{60} sample at T=5K and the closed squares for the ^{7}Be@C_{60} at T=293K, the closed circle for the ^{7}Be@C_{70} at T=293K, further, the cross symbols for the Be metal(^{7}Be) at T=293K. The half-lives in these samples are indicated in the figure. It was surprising to note that the half-life of ^{7}Be in the ^{7}Be@C_{60} at T=5K and that in the Be metal(^{7}Be) at T=293K was dramatically different by almost 1.5% as shown in Fig. 1[5]. It can be clearly seen in the figure that the half-life of ^{7}Be in the $^{7}Be@C_{60}$ at T=5K is 0.34% shorter than that in the $^{7}Be@C_{60}$ at T=293K. Furthermore, we newly found that the half-life of ^{7}Be in the $^{7}Be@C_{70}$ at T=293K is almost corresponding to that of the $^{7}Be@C_{60}$ at T=5K. Now we are continue to measure the half-life of ^{7}Be in the $^{7}Be@C_{70}$ at T=5K.

References

1) Segr'e E., Phys. Rev. **71** (1947) 274.
2) Ohtsuki T., et al., Phys. Rev. Lett. **93** (2004) 112501.
3) Ohtsuki T., et al., Phys. Rev. Lett. **77** (1996) 3522.
4) Ohtsuki T., et al., Phys. Rev. Lett. **81** (1998) 967.
5) Ohtsuki T., et al., Phys. Rev. Lett. **98** (2007) 252501.

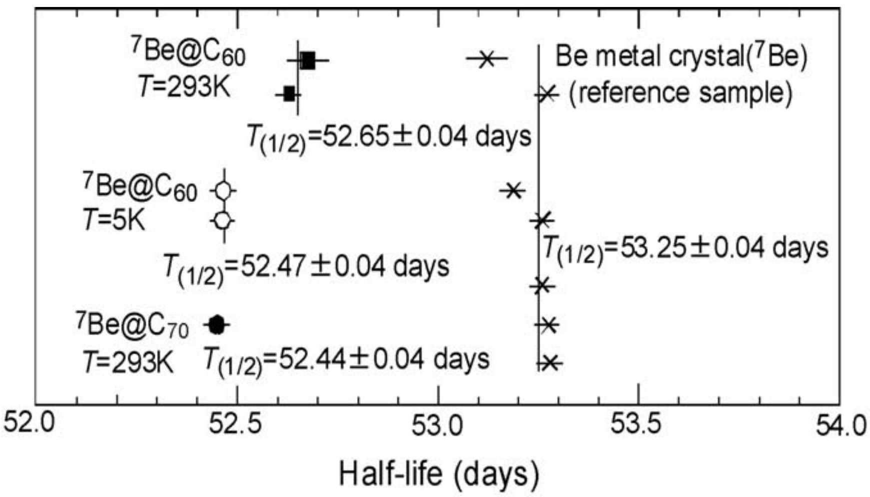

Figure 1. Half-lives are plotted: the open circles indicate the half-lives obtained for the $^{7}Be@C_{60}$ sample at T=5K, the closed squares for the $^{7}Be@C_{60}$ at T=293K, the closed circle for the $^{7}Be@C_{70}$ at T=293K, the cross symbols for the Be metal(^{7}Be) at T=293K.