Large Increase of ^{7}Be Decay Rate Under Compression

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Introduction

The decay rate of ^{7}Be is known to be susceptible to external environment and has been studied by implanting ^{7}Be in different media [1-4]. It was found that the electron affinity of the surrounding medium could change the decay rate of ^{7}Be by the fraction of a percent, because the valence 2s electronic orbital could be modified by the external medium and thus the electron density at the nucleus could be slightly changed. Density functional calculations can account for such effect reasonably well [2, 5].

There are only a few studies [6, 7] on the effect of compression on the decay rate of ^{7}Be and density functional calculations seem to underpredict the experimental results by a large factor. It is important to undertake more studies and understand these results, because of their astrophysical significance [8]. ^{7}Be electron capture process is going on in the solar core at a high pressure of 26.5 million GPa. Density functional calculations were performed [8,9] considering ^{7}Be ions immersed in the dense plasma of the solar core to calculate the electron density at ^{7}Be nucleus and its corresponding decay rate that affects ^{8}B solar neutrino flux. Since we cannot directly measure the decay rate of ^{7}Be in the solar core, it is important to check whether density functional calculations could explain the effect of compression on the decay rate of ^{7}Be at pressures achievable in the laboratory experiments.

We have experimentally measured the difference of decay rate of ^{7}Be implanted in the smaller spatial confinement of Pd lattice (face centered cubic lattice; lattice parameter=3.89Å) versus larger spatial confinement of Pb lattice (face-centered cubic lattice; lattice parameter=4.95Å). Since the electron affinity of Pd and Pb are very low and similar, any observed increase of ^{7}Be decay rate in Pd compared to that in Pb could be attributed to the compressional effect in the smaller confinement of Pd lattice. We can then find out if density functional calculations would account for the observed increase of decay rate in Pd lattice and look for other possibilities.

Experiment

^{7}Be ions with energies in the range of (1-3) MeV were produced by bombarding a 400 μg/cm^2 LiF target evaporated on 1.5μm thick aluminum foil by a 7 MeV (500 nA) proton beam from Variable Energy Cyclotron, Kolkata. These ^{7}Be ions were implanted in Pd and Pb foils placed behind LiF target. The implantation on each catcher foil was done for 10-12 hours. ^{7}Be implanted Pb or Pd foil along with a standard ^{60}Co source were counted by placing them in front of a high efficiency HPGe detector in a low background counting room. A precision electronic pulser was counted by a scaler and used as a clock. The counting continued for about 5 months.

Results

In the γ-ray spectrum of Pb catcher foil, the most prominent peaks are 477.6 keV peak from ^{7}Li obtained from the decay of ^{7}Be ($\tau_{1/2}$≈53.2 days) and two γ-ray peaks (1173.2 keV and 1332.5 keV) from ^{60}Co ($\tau_{1/2}$≈1925.3 days). In the γ-ray spectrum of Pd catcher foil, we see γ-ray lines from long-lived Pd isotopes in addition to γ-ray peaks from ^{60}Co and 477.6 keV γ-ray line from ^{7}Li. We also see all the expected natural background γ-ray lines. In Fig. 1(a, b), we show the exponential fits of the decay curves of ^{7}Be implanted in Pd and Pb. We plot time along X-axis and the ratio of the peak area of 477.6 keV line to the sum of the peak areas of ^{60}Co γ-ray lines along Y-axis to cancel out the effect of dead time of the data acquisition system. Reduced χ^2=1.1 and 0.9 have been obtained for the exponential fits. In Fig. 1(c, d), we show the residual plots for Pd and Pb. The residual plot is the difference between the actual data and corresponding exponential fit. In Fig. 1 (e, f), we show frequency plot. In these plots, the residual values are plotted along X-axis and frequency that is the number of data points (with the statistical error bars) in a specific bin around the corresponding residual value is plotted along Y-axis. Reasonable Gaussian fits with reduced χ^2 =1.11 and 1.08 imply that the fluctuations around zero in the residual plots are statistical and there is no significant systematic error.

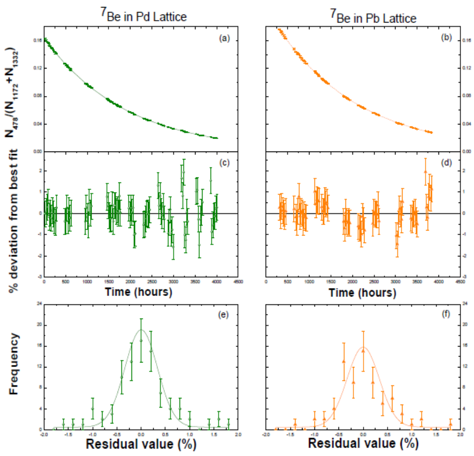

Fig. 1(a,b)**:**Exponential fits for the decay of ^{7}Be in Pd and Pb. Fig. 1(c,d): Residual plots; Fig. 1(e,f): frequency plots.

We find from the exponential plots that the decay rate of ^{7}Be in Pd is faster than that of ^{7}Be in Pb by **(0.82±0.16)%**.

Discussions

We have performed density functional WIEN2k calculations [10] by placing ^{7}Be in octahedral and tetrahedral positions of Pd and Pb lattices. The lattice distortion due to the insertion of ^{7}Be in the interstitial space was considered by minimizing force and energy on the lattice atoms. Our density functional calculations predict that the decay rate of ^{7}Be would increase by only ~0.2% in Pd lattice compared to that in Pb lattice, whereas, the corresponding experimental result is (0.82±0.16)%. The effects of finite nuclear size and quantum electrodynamics have been considered and they give negligible contributions for small ^{7}Be nucleus, as expected. Another possible effect is the measurement-induced increase of decay rate (quantum anti-Zeno effect), as the nuclear charge would be monitored more frequently by the valence 2s electrons in a ^{7}Be atom subjected to compression [11]. However, this effect is generally considered very small, because of the expected very short initial nonexponential decay time (~10^{-22} s) in the case of ^{7}Be decay. On the other hand, the duration of initial nonexponential decay time could be much longer in certain models of quantum measurement [12], implying an observable increase of ^{7}Be decay rate under compression.

It is important to understand the increase ^{7}Be decay rate under compression in laboratory experiments to obtain more confidence in the calculation of ^{7}Be decay rate at the solar core that is not directly accessible by experiment.

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