Does the α-decay rate change under lattice compression?

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Introduction

The radioactive decay rates are generally known to be independent of any change in the external environments such as the change in temperature or pressure. Among the various types of radioactive decays, orbital electron capturing nuclear β-decay rate is known to be slightly affected by the external environment. Small changes of the electron capture nuclear decay rate of ^{7}Be in different chemical environments and under compression have been observed in different experiments [1,2,3]. Both the increase of electron density at the nucleus and the increase of the energy of the emitted neutrino under compression could increase the decay rate of electron-capturing β-decay rate. So, such changes could be observed in ^{7}Be and for electron-capturing nuclei with low Q_{EC} values. However, the available measurements of the electron capture nuclear decay rate of radioactive atoms under compression shows a relatively higher percentage increase of the decay rate compared to the results of the electronic structure calculations of solids, performed by using density functional and Hartree-Fock techniques [4] and the reasons are still not understood.

The alpha decay rate under compression could change as the electron density around the nucleus increases and it drives a mechanism that changes alpha decay rate. Recent theoretical calculations indicate [5] that the fractional lifetime variation of alpha decay with respect to a bare alpha-emitting nucleus decreases slightly initially before increasing with applied pressure. ^{211}At nucleus emits α-particles and also undergoes electron capture (EC) decays with about the same decay constant ($\tau_{1/2}\approx$7.2 hours). If ^{211}At nuclei are implanted in a small lattice (Pd) and large lattice (Pb), a small decrease of α-decay rate (λ_α) in Pd compared to that in Pb is expected, whereas the EC decay rate (λ_{EC}) is expected to increase slightly in Pd versus Pb. So, there could be an observable increase of $\left[\frac{\lambda_{EC}-\lambda_\alpha}{\lambda_\alpha}\times 100\%\right]$ under lattice compression in Pd versus Pb. A series of experiments have been performed at VECC to observe any change of the quantity $\left[\frac{\lambda_{EC}-\lambda_\alpha}{\lambda_\alpha}\times 100\%\right]$ for ^{211}At under lattice compression in Pd versus Pb.

Experiment

^{211}At ions were produced by bombarding a natural bismuth film (~500μg/cm2) deposited on an aluminium foil (25 μm thick) with a 29 MeV $^4He^{2+}$ beam from the room temperature cyclotron at VECC, Kolkata. The energetic ^{211}At ions produced with an average kinetic energy of 0.5 MeV were implanted in Pd and Pb foils placed behind the bismuth film. ^{211}At nucleus emits α-particles with the energy of E_α =5869.5 keV and undergoes an electron capture process followed by prompt α-emission with the energies of 6568 keV, 6891 keV and 7450 keV. λ_α and λ_{EC} are about the same, having half-life ($\tau_{1/2}$=7.214 ± 0.007 hours). The emitted alpha particles were detected using an ion-implanted silicon surface barrier detector and monitored continuously for more than ten half-lives. The FWHM energy resolution of 30 keV was obtained for the α-peak at E_α=7450 keV. A standard pulse generator was used for the dead time correction of the VME Data Acquisition System. A succession of implantation runs over three half-lives using Pd or Pb catcher foils were taken and they were followed by data taking of 30 minutes durations. The data taking continued after saving the spectrum and the counting continued for over ten half-lives of ^{211}At. The experiment has been repeated four times so far to reduce the statistical error bars and to search for any possible systematic errors. More repeat experiments are planned to reduce the statistical error bars, because we are searching for a tiny effect.

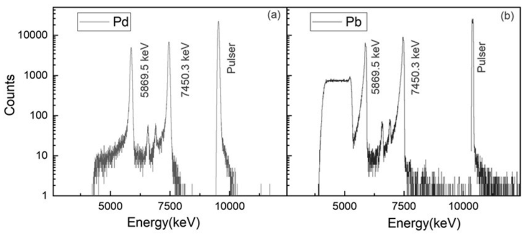

Fig. 1 (a,b): Typical α-spectra of ^{211}At implanted in Pd and Pb catcher foil.

Results

^{211}At nucleus has a 41.8% α-branching ratio $(E_\alpha = 5869.5\ keV)$ and an EC branching ratio of 58.2% followed by a prompt α-decay (half-life = 0.5 s). The half-lives of both the α branch and EC branch are the same (~7.214 hours). In the case of Pb catcher foil, α-emitting $(E_\alpha = 5304\ keV)$ ^{210}Po nuclei (half-life 138.37 days) are produced as a result of interaction between Pb and ^{4}He nuclei. A broad distribution of energy in Pb-catcher spectrum was observed as 5304 keV α-particles from ^{210}Po were emitted throughout the bulk of the thick 25 μm lead foil losing different amounts of the energies in the Pb catcher foil depending on the depth from where they originated. A background run was also carried out where 27 MeV α-beams from VEC were impinged directly on Pb and Pd foils to study the background spectra.

In Fig. 2(a,b), we show typical fits using the formula $Y(\text{counts}) = N_0 e^{-\lambda t} + Y_0$ for the decay curves of the ^{211}At nuclei implanted in Pd and Pb for one experimental run. We plot time (t) along X-axis and the dead time corrected peak area (Y) of 5869.5 keV alpha lines along Y-axis. Reduced χ^2=1.04 and 0.98 have been obtained for the exponential fits. The values of Y_0 are consistent with the results obtained from the background runs. Then Y_0 corrected ratios of the EC peak areas to α-peak areas were plotted versus time (t) and a liner fit was done. Finally, the quantity $\left[\frac{\lambda_{EC}-\lambda_\alpha}{\lambda_\alpha} \times 100\%\right]$ was extracted. At present, we have a preliminary result where the difference between the corresponding values of $\left[\frac{\lambda_{EC}-\lambda_\alpha}{\lambda_\alpha} \times 100\%\right]$ in Pd versus Pb is= $(0.070 \pm 0.024)\%$, where the uncertainty is statistical only.

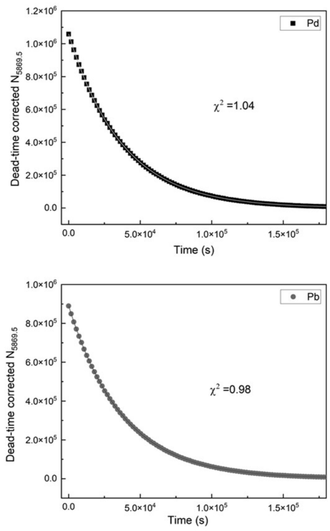

Fig. 2(a, b)**:** Exponential fits for ^{211}At in Pd and Pb.

Although we found variations in the absolute values of λ_α and λ_{EC}, the percentage difference of $\left[\frac{\lambda_{EC}-\lambda_\alpha}{\lambda_\alpha} \times 100\%\right]$ remained about the same and the systematic error seems to be negligible. The data analysis is still in progress to study any possible systematic errors and more experiments will be performed to improve the statistical error bar.

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References

[1] Y. Nir-El *et al.*, Phys. Rev. C**75**, 012801 (R) (2007).
[2] W. K. Hensley *et al.*, Science **181**, 1164 (1973).
[3]A. Ray *et al.*, Phys. Rev. C **101,** 035801(2020).
[4] A. Ray *et al.*, Eur. Phys. J. D **75**, 140 (2021).
[5] F. Belloni, Eur. Phys. J. A **52**, 32 (2016).