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Study of ^{74}As decay in different host materials and at different temperatures

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The branching ratio between the β^- and β^+/ε decay of ^{74}As has been measured in Ta, Al, Ge and mylar. The decay in Ge and Ta samples has also been studied at different temperatures in the range of 250 mK to 300 K. No significant dependence either on the temperature or on the host materials has been found. Our work demonstrates the inadequacy of the Debye – Hückel model in explaining similar experiments, confirming the recent results of the field.

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1. Introduction

Studies of the d(d,p)t reaction showed that the electron screening phenomenon is strongly enhanced in metallic environment [1, e.g.]. An idea had arisen recently that the electron cloud surrounding a nucleus may also affect the decay half-life of radioactive nuclides in a metallic environment [2]. The emission of positively charged particles (α or β^+) can be enhanced by the electron cloud resulting in a reduced half-life, while longer half-life is predicted for negatively charged particle (β^-) emission.

Though numerous recent experiments showed no half-life dependence on the host material or on the temperature [3, e.g.], there are several experimental results claiming to confirm the hypothesis that the electron screening has notable effect on the half-life of radioactive nuclides [4, e.g.].

Calculations based both on the dielectric function method [5] and on the classical plasma theory of Debye [6] had been performed. These models give a reasonably good qualitative description of the enhanced electron screening phenomenon, though they fail to reproduce the absolute value of the screening energy. The applicability of the Debye-Hückel screening model is also questionable on the theoretical side, since the approximations used in the model can only be applied to weakly coupled plasma and to much higher temperatures than the temperatures used in the performed experiments (room temperature and below). The dielectric function method predicts a slight temperature dependence of the half-lives, while the Debye-Hückel model predicts a $\propto \frac{1}{\sqrt{T}}$ temperature dependence, which should become very significant at low temperatures.

The aim of our experiments was to investigate the host material and temperature dependence of the possible effect of electron screening on half-lives at very low temperatures using a novel technique introduced in [7].

2. The decay of ^{74}As

In order to reduce the systematic error coming from geometrical effects of the measurement, we investigated the decay of ^{74}As. This isotope undergoes either a β^- or a β^+/ε decay. The simplified decay scheme of ^{74}As can be seen in the left panel of Fig. 1. The β^- decay leads to ^{74}Se with a branching ratio of $I_{\beta^-} = 34 \pm 2\%$, while the β^+/ε decay produces ^{74}Ge with $I_{\beta^+/\varepsilon} = 66 \pm 2\%$. Both decays are succeeded by strong γ-radiation due to the de-excitation of the decay-daughters. The β^- decay is followed by an $E_\gamma = 634.8$ keV radiation (with a relative intensity of $15.5 \pm 1.2\%$) and the β^+/ε decay by an $E_\gamma = 595.8$ keV radiation ($59.4 \pm 3.5\%$ relative intensity) [8]. Since the electron screening theory predicts an opposite effect on the β^- and β^+ decays, the measurement of the intensity ratio of the above two γ-radiations should be a sensitive probe of the screening effect on the decay with a highly reduced systematic error.

We have measured the intensity ratio of the 595.8 keV and 634.8 keV peaks of ^{74}As implanted into insulator mylar, semiconductor Germanium and metallic Aluminium and Tantalum. We have also performed the ^{74}As in Ge and the ^{74}As in Ta measurements at different temperatures to verify the predicted temperature dependence of the decay rate.

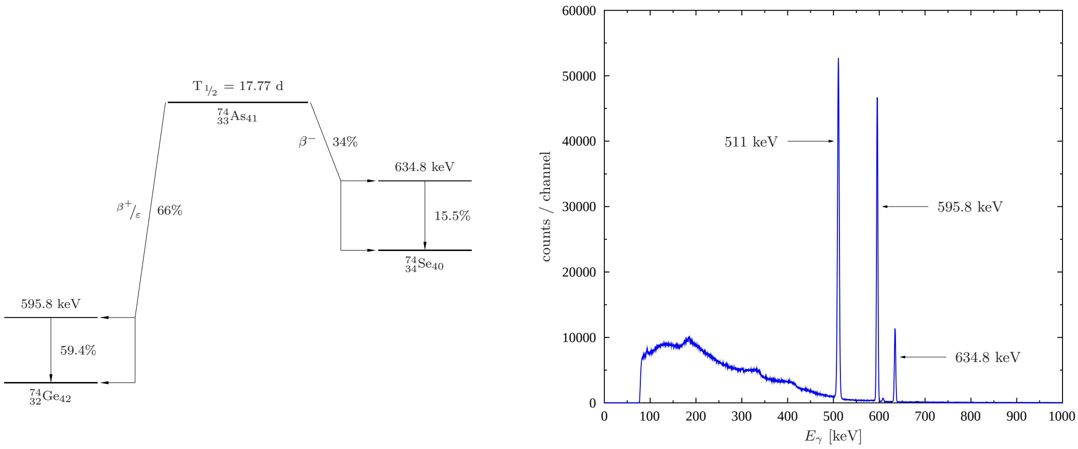

Figure 1: Left panel: The simplified decay scheme of ^{74}As, showing only the relevant transitions. Right panel: γ-spectrum of ^{74}As embedded into natural Ge, cooled down to 1.4 ± 0.2 K. The measurement started 73 hours after the source preparation and took 1.7 hours.

3. Measurement at room temperature

The experimental technique and the results of the room temperature experiments have already been presented elsewhere [7]. Some details of the experiment are briefly recalled here.

The ^{74}As sources have been produced using the cyclotron of the ATOMKI. A 10.2 MeV proton beam with 1 μA intensity bombarded a thin Ge target, inducing the ^{74}Ge(p,n)^{74}As reaction. The target was prepared by evaporating natural Ge onto a 3 μm thick Al foil. The thickness of the Ge layer was roughly 50 μg/cm^2. The produced ^{74}As nuclei are in part stopped in the Ge target while the high energy part leaves the Ge layer and gets implanted into the 0.5 mm thick Al or Ta host material placed behind the production target. The implanted surface was 15 mm in diameter. The host material served also as the beam-stop and was directly water cooled. In the left panel of Fig. 2 the schematic layout of the setup used for the sample production is shown. To implant ^{74}As into an insulator, the chamber has been extended behind the production target and the inner surface of the cylindrical extension has been covered with an 8 μm thick mylar foil. After the implantation, the mylar foil has been folded and fixed in a holder providing approximately the same source geometry as in the case of the metallic sources. The Ge target itself was used as the source to study the decay of ^{74}As in Germanium. In this case the sample size was estimated from the lateral beam size to be 8 mm in diameter.

The γ-counting has been carried out with a shielded 40% relative efficiency HPGe detector. The intensities of the two studied γ-lines have been measured with better than 0.5% statistical uncertainty. We observed no disturbing γ-activity in the samples.

4. Low temperature measurement

The decay of ^{74}As in Ta and Ge host materials has also been studied at low temperature. The sources for this experiment have been prepared the same way as described above.

The γ-counting has been carried out in the cryogenic laboratory of the ATOMKI. The schematic view of the dilution refrigerator used to cool down the samples to the millikelvin range can be seen in the right panel of Fig. 2. Liquid N_2 and liquid ^{4}He were used to take the temperature of the source down to 4.2 K. The sample holder was connected to the ^{3}He-^{4}He mixing chamber by a copper cold finger, making it possible for the sample to reach the millikelvin temperature range. The γ-rays created by the de-excitation of the daughter nuclei of ^{74}As could escape the chamber of the sample holder through three Aluminium windows.

A 20 % relative efficiency HPGe detector has been used to detect the γ-activity of the samples. The γ-detector had been placed directly in front of the outmost window. The diameter of this window was 7.9 cm, which was approximately the same as the diameter of the detector end cap. The distance between the source and the sensitive volume of the detector was 8.8 cm, making the summing effects negligible. The right panel of Fig. 1 presents a typical γ-spectrum measured on the Germanium sample at 1.4 K temperature.

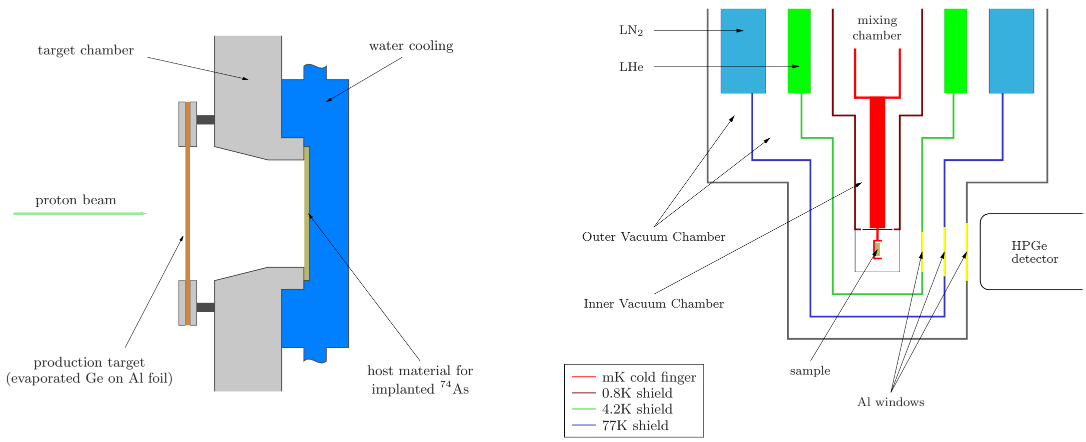

Figure 2: Left panel: Schematic view of the setup used to produce implanted ^{74}As samples. Right panel: Schematic view of the setup used for the low temperature measurements.

5. Results and conclusions

The measured intensity ratios of the 595 and 635 keV peaks at room temperature for the four different host materials can be seen in the left panel of Fig. 3. The ratios are normalized to the one measured in the insulator mylar sample where no enhanced electron screening is expected. The low temperature measurement results are plotted in the right panel of Fig. 3, where the peak ratios are normalized to their value at 300 K.

Though the results for the room temperature experiment show a slight indication that the decay branching ratio is smaller for metallic samples compared with the insulator mylar, the assumption of no dependence on the host material is well within two sigma errors of the measured points. The millikelvin measurements for the Germanium embedded Arsenic firmly shows no temperature dependence of the branching ratio. The source activity of the Ta sample was rather low, therefore the gamma measurement here has much worse statistics, but the assumption of null dependence on the temperature is still within two sigma errors.

The present results confirm that the Debye-Hückel model is inadequate in describing the decay of embedded nuclei. In the future we plan to re-measure the Tantalum sample with better statistics.

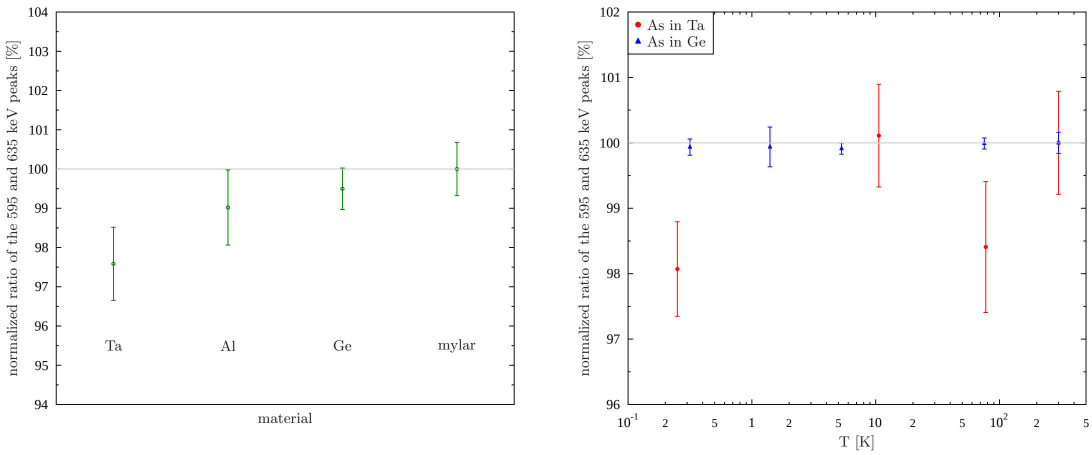

Figure 3: Left panel: The normalized ratio of the counts in the 595 and 635 keV peaks measured at room temperature. ^{74}As is embedded into Ta, Al, Ge and mylar, respectively. Right panel: The normalized ratio of the counts in the 595 and 635 keV peaks, at different temperatures for Ge and Ta samples.

Acknowledgments

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References

[1] F. Raiola *et al.*, Phys. Lett. B **547**, 193 (2002).

[2] F. Raiola *et al.*, J. Phys. G **31**, 1141 (2005).

[3] V. Kumar, M. Hass, Y. Nir-El, G. Haquin and Y. Yungreiss, Phys. Rev. C **77** 051304(R) (2008).

[4] T. Spillane *et al.*, Eur. Phys. J. A **31**, 203 (2007).

[5] K. Czerski, A. Huke, P. Heide and G. Ruprecht, Europhys. Lett. **68** 363 (2004)

[6] F. Raiola *et al.*, Eur. Phys. J. A **19**, 283 (2004).

[7] Gy. Gyürky *et al.*, Europhys. Lett. **83/4**, 42001-p1 (2008).

[8] B. Singh, A.R. Farhan, Nucl. Data Sheets **107**, 1923 (2006).