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MEASUREMENT OF THE HALF-LIFE OF ^{8}Li

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The β-decay half-life of ^{8}Li has been measured along with in a β-NMR experiment, using thermal ^{8}Li atoms adsorbed in ultra high vacuum on a silicon single crystal surface. A special hardware-based scaler electronics was used to circumvent part of the dead time corrections. The half-life is found to be (839.60 ± 1.06) ms, in accordance with previous experiments.

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1. Introduction

This brief contribution reports on a new measurement of the half-life of ^{8}Li using thermal ^{8}Li atoms adsorbed on a Si(111) single crystal surface ($T = 310$ K). The data are a byproduct of β-NMR experiments on single crystal surfaces using nuclear spin polarized ^{8}Li atoms as adsorbates [1–6]. But, for the experiment here, only unpolarized ^{8}Li atoms were used. The half-life of ^{8}Li is of importance for the investigation of Gamow–Teller β-decays in light nuclei [7–9] and in the study of its β-decay mechanisms [10, 11]. Furthermore, it is of astrophysical interest since ^{8}Li serves partly as a doorway for primordial element production [12].

2. Experimental

The experimental setup used was described in the past several times in detail [1, 2, 6, 13] (see Fig. 1). We use 24 MeV $^7Li^{3+}$–ions from the MP–Tandem accelerator of the Max–Planck–Institut for Nuclear Physics in Heidelberg, where Nikola Cindro was always a wellcomed guest. The ions impinge on a high pressure/low temperature (6 bar at 77 K) deuterium gas target to produce ^{8}Li via the ^{2}H(^{7}Li,^{8}Li)^{1}H-stripping reaction. Inverse kinematics is applied to direct all ^{8}Li reaction products within a narrow cone onto the thermalizer. In the current context, the use of a thermalizer allows to separate the production and stopping area of the ^{8}Li from the actual measurement section of the experiment, reducing the final background considerably (no activation). The thermalizer consists of a graphite tube, heated to high enough temperature (1700 °C) so that the implanted ^{8}Li (and ^{7}Li) ions reach quickly the graphite surface through diffusion [6]. They desorb from the graphite surface predominantly as atoms due to their larger ionization energy as compared to the graphite workfunction. By the tube geometry and through several apertures, not shown in Fig. 1, a homogeneous atomic beam is formed, consisting of about 1.2×10^4 ^{8}Li/s and 10^5 times more ^{7}Li at the surface 0.6 m apart from the thermalizer exit. The optical pumping devices (laser), which are used to polarize the ^{8}Li atoms do not matter here, except for the fact that they need space and thus reduce the ^{8}Li intensity at the surface where they adsorb. To avoid trailing effects of the tubular thermalizer on the time structure of the atomic beam a mechanical shutter is used additionally (Fig. 1).

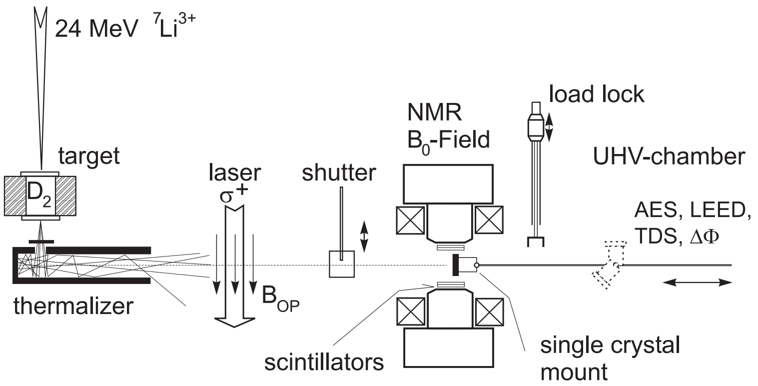

Fig. 1. A schematic drawing (not to scale) of the major components of the ^{8}Li *source together with the* β*-electron detection in the magnetic field of the UHV chamber of the surface experiments. The analytical tools to the right of the surface were not used. The magnetic field was furthermore switched off.*

Data were taken in a cyclical mode in which the ^{7}Li beam impinged on the D_2–gas target for 3.0 s activation time. A meaningful detection of the events started about 50 ms after the ^{7}Li–ion beam was deflected and dumped far away from the ^{8}Li source. The background generated by the 24 MeV ^{7}Li beam faded quickly enough that it contributed always less than 10^{-3} to the events stemming from the ^{8}Li decay. Counting continued then for more than 13 s, until the ^{7}Li beam was restored.

The decay of the ^{8}Li nuclei is detected by observing the decay electrons (endpoint energy 12.45 MeV [8]) with a telescope covering about 20% of the solid angle. (For the NMR experiments two were installed since in that case the decay asymmetry with respect to the polarization direction is of interest.) Because of their high endpoint energy, most of the electrons have minimum ionization efficiency. To detect those electrons, a plastic scintillator telescope consisting of two scintillators (NE104) in coincidence is sufficient. In order to allow for the surface science experiments to bake it, it resides outside the UHV-chamber and the electrons reach it from inside through a thin stainless steel windows in the chamber (1.4429 esu, 150 μm). About 230 keV are lost in the 150 μm window, 180 keV are dumped in the packaging of the scintillators (Al/polyvinyle), and about 370 keV are deposited within the first scintillator material, in total 1.51 MeV. Thus, approximately 95% of all β-electrons trigger a coincidence signal. (For further details of the detection system, including the coupling of the scintillators to the photomultipliers via flexible light guides, see Sect. VIII in Ref. [1].)

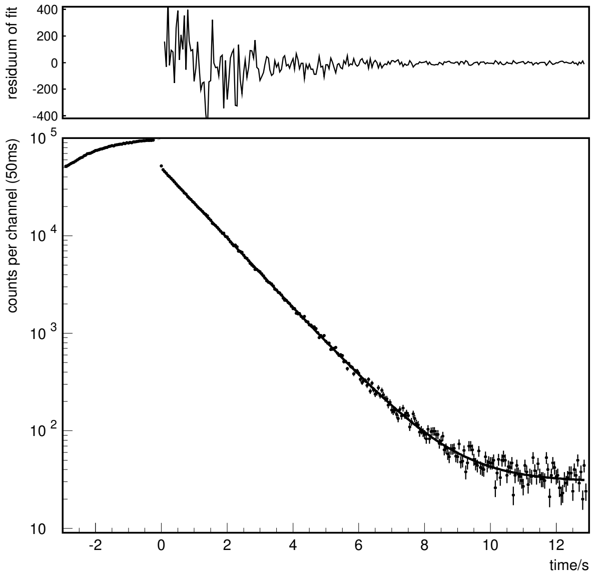

Fig. 2. Lower part: Time dependence of the electron count rate of the telescope. The counts for $t < 0$ are mainly due to activity coming from the 24 MeV ^{7}Li *beam. It is deflected at $t = -22$ ms. Meaningful data take starts at $t = 50$ ms. Upper part: Difference spectrum (residuum of fit) for $t > 0$ between data and fit (lower part).*

Limitation of the accuracy of the final results comes from several sources, the easiest one to be tackled being the statistical accuracy of the data and background corrections. The latter are well under control due to the long time period of 13 s the ^{8}Li decay was measured (Fig. 2, lower part). Errors in the time calibration may be a further accuracy limiting aspect. For timing, we used a HP Model 3325B

Synthesizer/Function Generator, acting as a precision pulser (bin width 50 ms; see Fig. 3). At its purchase 12 years ago, 6 years before the experiment, its calibrated relative accuracy amounted to $\pm 5 \times 10^{-6}$ with a maximum annual shift of also $\pm 5 \times 10^{-6}$/year. Recalibrating this clock recently against a freshly calibrated Fluke 164T MultiFunction counter showed an absolute (time) discrepancy of $+4.5 \times 10^{-6}$ with an uncertainty of $\pm 1.1 \times 10^{-6}$ at 40 Hz and $\pm 1 \times 10^{-8}$ at 1 MHz. The Fluke 164T calibration itself amounts absolutely to $\pm 1.6 \times 10^{-6}$. Thus errors due to timing are much smaller than the relative statistical error finally achieved (1×10^{-3}).

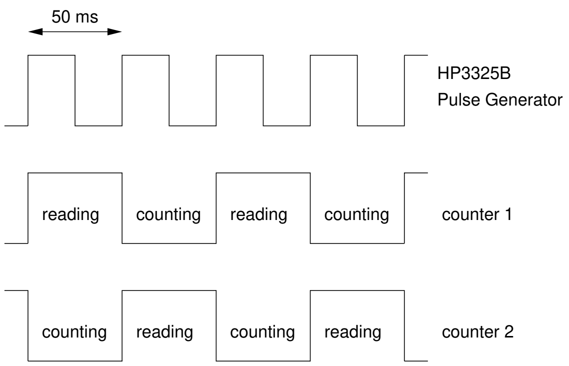

Fig. 3. Timing sequence used to abandon dead time corrections.

By far the largest limitation of accuracy, however, may come from the dead time corrections. (See in particular the discussion in Ref. [14]). With the present setup, there are two sources: dead time corrections for the generation of the coincidence signal and dead time corrections for counting finally the coincidence events. For the latter, a special scaler electronics was implemented. It consisted basically of a 100 MHz–Camac pulse shape electronic unit and two PC–based hardware gated scalers. While one scaler is used in a 50 ms interval for counting, the other is read out by the PC, and vice versa (see Fig. 3). The external 20 Hz gating was performed by the HP Model 3325B Synthesizer/Function Generator and a flip–flop integrated circuit (IC) logic (7470, 7400) with short switching times (15 – 22 ns). The setup was tested with another HP pulser, instead of a β-emitter. A 1 MHz pulse was counted in parallel, in order to monitor faults. Deviations display a Gaussian-distribution which becomes smaller the more runs are added. Thus, these deviations affect the data in an entirely statistical manner and these corrections can be neglected compared to the statistical error achieved finally.

However, the formation of the coincidence signal is affected by the dead time corrections due to a finite coincidence resolution time Δt. Since the experimental data were taken 6 years ago, without the care to minimize the dead time problem, we just include this correction in form of an additional error of the final result, even though it probably overestimates by far the real error due to the dead time correction. The counts in each single scintillator showed within a few permille the same time dependence as the coincidence rate, Eq. (1). Dead time corrections are the largest for initial times, where the count rate of each single counter is the highest (about $Z(t = 0) = 8000/\mathrm{s}$). Taking into account the finite coincidence resolution time of $\Delta t \simeq 15$ ns and expanding the loss in counts at short time linearly, we finally end up with a correction (maximum error) of the decay constant of $\Delta\lambda/\lambda \leq 2Z(t = 0)\Delta t \simeq 0.24 \times 10^{-3}$.

3. *Results and discussion*

The lower part of Fig. 2 displays the decay electron (coincidence) counts as a function of time. A fit to the data, allowing for a constant background,

$$N(t) = N_0 e^{-\lambda t} + c = N_0 e^{-t/\tau} + c \tag{1}$$

results in a half-life $T_{1/2} = \tau \ln 2 = 839.60$ ms with a relative error of 1.02×10^{-3}. The difference spectrum (residuum) between data and fit, displayed in the upper part of Fig. 2, is purely statistical and does not indicate any other correlated time dependence. Taking additionally into account the maximum error due to the dead time while forming the coincidence signal (0.24×10^{-3}), we obtain as maximum relative error 1.26×10^{-3}, just by adding up the two contributions. This yields as final result for the half-life of ^{8}Li

$$T_{1/2} = (839.60 \pm 1.06) \text{ ms} . \tag{2}$$

(To identify this value with the total decay rate of ^{8}Li, it is assumed that ^{8}Li decays entirely through the broad $^8\mathrm{Be}(2^+)$ level at 3.04 MeV [8].)

The final result agrees well with $T_{1/2} = (839.9 \pm 0.9)$ ms, quoted in the preliminary version of the compilation "Energy Levels of Light Nuclei $A = 8$" [8]. This value was obtained as a weighted average over three results obtained since 1971: (840.3 ± 0.9) ms, (838 ± 6) ms and (836 ± 3) ms from Refs. [10], [14] and [15], respectively. Our result agrees also favourably with each of these individual results. In this context, it is worthwhile to be mentioned that the agreement with the up to date most precise result of Sale et al. [14] demonstrates convincingly our success to handle the dead time problems. Sale et al. report that even though their count rate was kept low, they would have obtained a 6 ms (!) higher half-life, had they not corrected their data for dead-time effects. Failure to take into account dead time corrections is therefore probably the reason why another result [16] $T_{1/2} = (844 \pm 0.7)$ ms is at odds with the experimental results discussed above.

Since handling of dead times and statistical errors are the essentials to increase the precision of the measured half-life, a new, devoted experiment is planned for the near future, in which the accuracy can be improved by about an order of magnitude.

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MJERENJE VREMENA POLURASPADA ^{8}Li

Mjerili smo vrijeme poluraspada u β-raspadu ^{8}Li (uz eksperiment β-NMR) rabeći termičke ^{8}Li atome koji su bili adsorbirani na površini monokristala Si u ultravisokom vakuumu. Primijenili smo poseban elektronički brojački sustav radi izbjegavanja dijela popravki za mrtvo vrijeme. Ishod za vrijeme poluraspada je (839.60 ± 1.06) ms, i on je u skladu s ranijim mjerenjima.