AN EXPERIMENTAL STUDY OF THE (μ⁺He)⁺ LIFETIME IN THE METASTABLE 2S-STATE USING NaI-CRYSTALS

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1. Introduction

The level structure of the first excited states of muonic helium isotopes has attracted physics interest since more than twenty years. From the viewpoint of physics theory the fine structure, hyperfine structure and in particular the Lambshift of this two body bound state are excellent testing grounds for quantum electrodynamics. Experimentally, laser spectroscopy, a precision tool in atomic physics, can here be transferred to a fundamental structure in a muonic atom, hence providing accurate measurements for theory to compare with.

Application of laser spectroscopy relies on some metastability of the 2S-state of the muonic helium ion within the buffer gas, where its formation conventionally takes place. For this reason the 2S-lifetime was the subject of many experimental\textsuperscript{1-6} and theoretical\textsuperscript{7-13} investigations. First measurements carried out at CERN\textsuperscript{14} indicate that the influence of the surrounding helium atoms is small even at pressures up to 50 atmospheres and that the 2S-lifetime at such high densities differs only slightly from the free, unperturbed ion. The 2S-2P energy differences determined there after by laser resonance excitation\textsuperscript{14-15} are in good agreement with theory, a result which requires the 2S-state to be metastable around 500 ns. Nevertheless, the experimentally established long lifetime of the 2S-state is in contradiction to theoretical calculations as well as recent experimental results. Since Lambshift measurements in the muonic helium(3) ion have not yet been performed, a better understanding of the 2S-lifetime especially at high pressure is quiet important. The fact that the CERN data seem not to reconcile with the body of new data from SIN, strengthened our assessment to redo the experiment with an apparatus which resembles the one from CERN in particular, by using NaI crystals.

*Electromagnetic Cascade and Chemistry of Exotic Atoms*
2. Experimental

A complete account of the experimental method has been given elsewhere\textsuperscript{16}. In brief, negative muons are stopped in gaseous helium, and the photons from the radiative transitions of the cascade are monitored. This “light” from the muonic cascade splits into a prompt and delayed component. The fast part is used to compute the formation fraction of the 2S-state, the slow part consists of a continuous spectrum from retarded one- and two-photon decays of the metastable 2S-state. The goal is to measure the time distribution of these photons relative to the incoming muon.

Fig. 1 shows the experimental set-up. Incoming negative muons are detected by the plastic scintillators $S_1$ and $S_2$, actively confined by the veto counter $SA$ to a spotsize of 18 mm. After passing a 0.1 mm thick beryllium-copper foil and an energy loss surface barrier detector (205 $\mu$m) the muons stop in the target gas of about 1000 cm$^3$ volume. Twelve NaI crystals (size $40 \times 40 \times 1$ mm$^3$) cover $0.45 \times 4\pi$ solid angle of the gas volume. They monitor the prompt cascade photons, the delayed ones from radiative 2S-1S transitions and the decay electrons from the subsequent muon decay.

The target vessel was built of stainless steel and coated with a thin layer of silver to suppress low energy characteristic x-rays from the wall materials. Together with all target components it was tested to resist a pressure of 80 atmospheres, and after being pumped to a rest gas pressure of $5 \times 10^{-5}$ mbar, was filled with 40 atmospheres of helium (4) at room temperature under normal running conditions. Gas impurities at a very low level might have a great influence on the lifetime of the 2S-state, therefore special care was taken to prevent gas contaminations caused by outgasing materials. For this reason, the light guides of the NaI crystals consist of optical glass. The crystals themselves were only covered with an 0.1 $\mu$m thick vapour deposited aluminium layer to avoid optical cross talk and a 0.05 $\mu$m thick SiO$_2$ protection layer to avoid oxidation of the aluminium. The helium gas was continuously circulated through a purification system consisting of a titanium getter heated to 800 °C and a cold trap at liquid nitrogen temperature. A quadrupol mass spectrometer was used to analyse the gas during the measurements. The main contamination was found to be 3 ppm neon, a component of the used helium gas which could not be removed by the purification system. All other contaminations, especially water vapour or nitrogen, were less than 1 ppm.

The measurements were carried out at the $\mu$E4 channel of SIN. The incoming muons at 33 MeV/c momentum was limited to a rate of 100 s$^{-1}$. At any time, only one single muon was allowed to be in the apparatus and was observed individually. A triggered event consisted of a muon stopped, followed by at least two hits in NaI crystals. Then