MUONIC X-RAYS AND MUON CAPTURE IN LOW-PRESSURE ARGON

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ABSTRACT

We have measured the spectrum of the K X-rays produced by muons stopping in low-pressure argon gas doped with 5% of propane.

We report a new value for the nuclear capture rate of negative muons in argon:

$$\Lambda_c(\text{Ar}) = (1.41 \pm 0.11) \times 10^6 \text{ s}^{-1} .$$

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Experiment SC74 was performed at the muon channel of the CERN 600 MeV SC, to measure the population and the lifetime of the 2S state of muonic hydrogen (μp), via the transfer reaction

The time distribution of the μAr characteristic X-rays with respect to the μ -stop time supplies information about the 2S state of the μp atom [1].

We have analysed the calibration runs, and we report here a measurement of the muonic electromagnetic cascade in gaseous argon ($P = 3$ and 6 abs atm) and a new value for the nuclear capture rate of negative muons in argon.

The 115 MeV/c negative muon beam had an intensity of about 30,000 particles per second, over an area of $\sim 40 \text{ cm}^2$. The muons were stopped in a stainless steel vessel filled with an argon-propane mixture (95% Ar, 5% C_3H_8) at pressures of 3 and 6 abs atm and ambient temperature. The experimental set-up is shown in fig. 1.

The beam telescope is made from scintillation counters 1-3. α is a proportional counter working in the same target gas and consists of three planes of 50 μm tungsten wire. A beryllium moderator (20 mm thick) is mounted inside the vessel, upstream of the proportional counter.

Counters A_1 - A_8 are plastic scintillators completely surrounding the vessel. These counters were used both to veto the muons passing through the vessel and to detect the muon decay electrons. Counters X_1 - X_8 are 4 in. $\times$ 4 in. NaI(Tl) crystals, each viewed by an XP-2040/2041 photomultiplier, and they were used to detect the muonic X-rays.

A $(1,2,3) \cdot \alpha \cdot \overline{\sum_1 A_i}$ (= STOP) coincidence signalled the stopping of the muon inside the target. In order to reduce the background caused by muons stopping in the target walls, we accepted only those muons giving a signal in counter α larger than a preset value. The accepted muons had a residual range less than 25 cm of gas. The α counter was calibrated with the electrons contaminating the beam.

The STOP signal opened a 10 μs wide gate during which X-ray signals (pulses in the NaI crystals) and electron signals (pulses in counters A_1 - A_8) were recorded.

To reduce accidental background, all STOP signals that were preceded within 8 μ s by another incoming particle (1,2,3) were ignored.

A pulse of any of the eight NaI counters during the gate interval caused the following quantities to be recorded on magnetic tape:

- 1) the amplitude of all the X-ray pulses within the gate;
- 2) the time of all the X-ray pulses within the gate;
- 3) the time of arrival of the decay electron (if any);
- 4) the amplitude of the α counter pulse;
- 5) the content of the various scalers.

The times and the amplitudes of the X-ray pulses were measured by eight TDC + ADC channels. The TDCs were started by the STOP signal. The time resolution for the X-rays was 3 ns FWHM; the amplitude resolution at 644 keV (K_α line of μ Ar) was better than 12% FWHM. The average efficiency for the K X-rays of μ Ar was (including solid angles) $\sim 0.1\%$ per counter.

Figure 2 shows the X-ray energy spectrum recorded at 3 and 6 abs atm by selecting only those X-rays in a 10 ns window immediately following the STOP signal (prompt X-rays). The spectrum was analysed by fitting three Gaussian line shapes α , β , ν to the K lines. Owing to the finite energy resolution of the counters, only one Gaussian was found to describe adequately all the K_γ , ..., K_∞ lines. From the fit we obtained the intensities of the various lines and the intensity ratios $J_\beta = K_\beta/K_\alpha$ and $J_\nu = K_\nu/K_\alpha$; these results are summarized in table 1. The comparison with previous results [2,3] suggests that the dependence of J_β , J_ν upon the pressure is not simple.

Next we analysed those X-rays coming at least 20 ns after the prompt peak (delayed X-rays). Owing to the low statistics, we have summed the results of the 3 and 6 abs atm runs. The spectrum in fig. 3 shows clear evidence for two peaks, centred around 644 keV and 845 keV, respectively. This spectrum is typical of light muonic atoms formed through a transfer process [2-4], the lines K_β , K_ν being

strongly enhanced with respect to the direct capture (see table 1). The ratio $K_{\text{delayed}}/K_{\text{prompt}}$ is about 0.15. Since the target gas contains 5% of C_3H_8 , a fraction of the muons is captured by hydrogen and could then be transferred to argon. By comparing two spectra taken in different time intervals we estimate a lifetime of the order of 250 ns for the delayed component. Such a value for a transfer process is surprisingly large and further investigations are in progress.

Figure 4 shows the time spectrum of the muon decay electrons that followed the emission of a prompt K_{α} X-ray. The exponential decrease corresponds to a lifetime of negative muons in argon,

$$\tau = 537 \pm 32 \text{ ns} ,$$

and the corresponding nuclear capture rate,

$$\Lambda_c(\text{Ar}) = (1.41 \pm 0.11) \times 10^6 \text{ s}^{-1} ,$$

in fair agreement with a previous result [5]

$$\Lambda_c(\text{Ar}) = (1.20 \pm 0.08) \times 10^6 \text{ s}^{-1} .$$

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Table 1

Experimental intensity ratios

Argon pressure (abs atm)	J_{β} $\times 10^2$	J_{ν} $\times 10^2$	$J_{\beta} + J_{\nu}$ $\times 10^2$	Reference
1000	5.1 ± 1.9	6.2 ± 2.3	11.3 ± 3.0	2
80	7.0 ± 1.0	9.0 ± 1.0	16.0 ± 1.6	3
10	9.0 ± 1.0	8.0 ± 1.0	17.0 ± 1.6	3
6	4.1 ± 0.5	4.7 ± 0.5	8.9 ± 0.7	This work
3	5.5 ± 1.0	5.8 ± 0.9	11.4 ± 1.4	This work

Figure captions

- Fig. 1 : Schematic view of the apparatus: 1,2,3 = beam telescope; 4 = NaI(Tl) crystals (counters $X_1 \dots X_8$); 5 = proportional counter (counter α); 6 = stainless steel vessel; 7 = anticoincidence shield (counters $A_1 \dots A_9$).
- Fig. 2 : Energy spectrum of the μ Ar prompt X-rays. 1 = 3 abs atm runs; 2 = 6 abs atm runs.
- Fig. 3 : Energy spectrum of the μ Ar X-rays detected between 80 and 180 ns after the STOP signal (delayed X-rays).
- Fig. 4 : Time spectrum of the μ -decay electrons. The fitted curve corresponds to a lifetime $\tau = 537 \pm 32$ ns, $\chi^2/\nu = 1.0$.

Fig. 1

Fig. 2

Fig. 3

Fig. 4