MEASUREMENT OF MUON PARTIAL CAPTURE RATES IN ^{16}O
AND THE INDUCED PSEUDOSCALAR COUPLING CONSTANT
IN MUON CAPTURE*)

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ABSTRACT

The partial rates in the capture of muons by ^{16}O were measured for the $J^\pi = 0^-$ and 1^- excited bound states of ^{16}N . The energy spectrum and the time dependence of the γ -rays emitted by the target were observed using a Ge(Li) detector. On the basis of the Rho-Migdal theory⁵⁾, the observed λ_0/λ_1 - ratio let for the induced pseudoscalar coupling to a value of $C_p = 10.6 \pm 1.0$.

Geneva - 21 January 1969

(Submitted to Physics Letters)

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The muon partial capture rate is most sensitive to the induced pseudo-scalar coupling constant in the case of a capture reaction between zero-spin nuclear states with opposite parities^{1,2)}. The capture of muons by ^{16}O can produce (among other possibilities) the two members of the $(1p_{1/2})p^{-1}(2s_{1/2})n^1$ doublet in ^{16}N : $0^{-}(120 \text{ keV})$ and $1^{-}(399 \text{ keV})$, with capture rates λ_{0-} and λ_{1-} , respectively. These quantities have been calculated in the framework of various nuclear models²⁻⁵⁾. The first one λ_{0-} was computed with the purpose of providing a C_p "detector", whilst the second one λ_{1-} , independent of C_p , was intended to serve as a cross-check of the theoretical ideas which were used.

Parallel to these calculations, experiments have been undertaken in order to determine these partial capture rates. Two results have been obtained^{6,7)} as shown in Table 1; they do not agree within the stated errors.

In these experiments, the de-excitation γ -rays in ^{16}N were detected with NaI(Tl) crystals.

The theoretical²⁻⁴⁾ and experimental^{6,7)} results for λ_{1-} remained in disagreement until Rho⁵⁾, on the basis of the Migdal theory, obtained values for λ_{1-} close to the experimental results. However, in spite of the success in predicting the λ_{1-} rate, the discrepancy between the two above-mentioned experimental λ_{0-} values did not allow the value of C_p to be specified.

The advent of new γ -ray detectors encouraged us to re-measure the λ_{0-} and λ_{1-} rates. The experiments were performed at the CERN Synchro-cyclotron muon channel. The target consisted of distilled water enclosed in a scintillator cup of $5 \times 6 \times 10 \text{ cm}$ (internal dimensions). The number of particles from the beam stopped in H_2O was measured by determining the stop rate with and without H_2O in the cup. It was shown by a time-of-flight measurement that 99% of the stopped particles were muons. The observation of the mesic X-rays and γ -rays subsequent to the stop of a particle in the target was started by the corresponding signal. This "start" signal was vetoed, however, if the stopped particle was preceded or followed by another stopped particle within $6 \mu\text{sec}$. In order to reduce the background, the γ -ray detector signal was rejected if the "start" signal was followed within $6 \mu\text{sec}$ by the electron from the

muon decay. Otherwise, the signal delivered by the 35 cm³ active volume Ge(Li) detector was used as "stop" signal for a time-to-pulse height converter. The energy spectrum and the time dependence of the resulting γ -rays were recorded with the aid of a multichannel pulse-height analyser (4096 channels operating in X-Y mode). The relative detection efficiency of the system in the energy range from 100 keV to 400 keV was measured by filling the target holder with a water solution of ⁷⁵Se. The absolute detection efficiency of the detection system was obtained by measuring the yield of the K-series X-rays in oxygen and magnesium. This yield was taken to be 100% ⁸⁾.

Figure 1 shows a γ -ray spectrum associated with the muons stopped in H₂O. This spectrum is one of the four statistically equivalent spectra taken during the experiment. Figure 2 shows the time dependence of the photopeak areas of the 120 keV and 276 keV γ -rays. The former is due to the decay of the 0⁻ isomeric state at 120 keV in ¹⁶N created in muon capture with a mean life of $\tau = 7.58 \pm 0.09 \mu\text{sec}$ ⁹⁾; the second represents the 1⁻ $\rightarrow$ 0⁻ transition in ¹⁶N, and displays a time dependence characteristic of the muon disappearance rate in ¹⁶O: $\lambda_{\text{disp}} = 5.12 \times 10^5 \text{ sec}^{-1}$ ¹⁰⁾.

Using the relative efficiency calibration of the detection system, and taking into account the fact that the 1⁻ state at 399 keV de-excites to the 0⁻ state with a $69 \pm 5\%$ probability ¹¹⁾, the ratio of the capture rates to the 0⁻ and 1⁻ states $\lambda_{0-}/\lambda_{1-}$ was readily obtained. The result is: $\lambda_{0-}/\lambda_{1-} = 0.46 \pm 0.04$. The error includes the statistical error, the error on the above quoted branching ratio and the error on the relative intensities of the ⁷⁵Se γ -rays ¹²⁾, i.e. that of the relative efficiency calibration. The result has been corrected for the inhomogeneous distribution of the particle stops in the target. The knowledge of the absolute detection efficiency and that of the number of effective (unvetoed) muon stops in H₂O which produced the 120 keV and 276 keV γ -rays enabled us to calculate the λ_{0-} and λ_{1-} rates separately. An estimate was also obtained for the rate of the third forbidden capture transition to the 3⁻ state in ¹⁶N at 299 keV. The results for λ_{0-} , λ_{1-} , and λ_{3-} are reported in Table 1, together with the previous results for these quantities. It should be emphasized at this point that the absolute rates we quote are subject to the assumed 100% yield of the calibration K-series X-rays. This assumption was shown to be correct with an uncertainty of 10% ⁸⁾.

Let us now compare the λ_{0-} rate and the $\lambda_{0-}/\lambda_{1-}$ ratio obtained in this work, with the corresponding theoretical predictions⁵⁾. In Fig. 3 are displayed both λ_{0-} and the ratio $\lambda_{0-}/\lambda_{1-}$ as a function of C_p and the corresponding experimental results [the experimental value of λ_{0-} was taken as $790 \leq \lambda_{0-} \text{ (sec}^{-1}\text{)} \leq 1000$, including the maximal uncertainty in the absolute efficiency calibration]. The theoretical curves were taken from the computation of Rho⁵⁾, including the velocity terms up to the second order; for the nuclear parameters his most realistic values were retained [$f_0' = 0.35$, $g_0' = 0.50$, $f_1' = -0.40$, and $g_1' = -0.10$]. From the comparison of the λ_{0-} rates, C_p turns out to be nearly the same as from the comparison of the $\lambda_{0-}/\lambda_{1-}$ ratios. The former comparison yields $10.5 \leq C_p \leq 13.0$ and the latter, $C_p = 10.6 \pm 1.0$. The latter value is to be considered as the more reliable one from the experimental point of view; moreover, the theoretical $\lambda_{0-}/\lambda_{1-}$ ratio is rather insensitive to the choice of the nuclear parameter values quoted in Ref. 5.

In conclusion, one may notice that the value of C_p obtained here is in agreement with the one deduced from the muon capture-rate measurements in atomic¹³⁾ and molecular hydrogen^{14,15)}.

We are indebted to J. Renuart, to the technicians of the Centre de Physique Nucléaire de Louvain, and to the CERN MSC Operation Group for their effective help which greatly contributed to the success of this work.

Table 1

The observed muon partial capture rates in the $^{16}\text{O} \rightarrow ^{16}\text{N}$ (bound states) reaction, compared to other experimental results and to the theoretical prediction calculated by Rho⁵⁾. The fourth column shows the value of C_p which is inferred in comparing the measured and the predicted λ_0^- -rate and the λ_0^-/λ_1^- -ratio. In the quoted errors of our results, the upper limit contains the intrinsic error of our measurement plus the absolute calibration uncertainty.

The observed quantities	Experimental results	Theoretical predictions ⁵⁾	C_p
λ_0^-	$850^{+60+85}_{-60} \text{ sec}^{-1}$, present work $1\,100 \pm 200 \text{ sec}^{-1}$ (Ref. 6) $1\,600 \pm 200 \text{ sec}^{-1}$ (Ref. 7)	Dependent on C_p	$12.3^{+0.7}_{-(0.7+1.0)}$ 9.6 ± 2 5.0 ± 1.5
λ_1	$1\,850^{+(170+185)}_{-170} \text{ sec}^{-1}$, present work $1\,880 \pm 100 \text{ sec}^{-1}$ (Ref. 6) a) $1\,400 \pm 200 \text{ sec}^{-1}$ (Ref. 7)	$2\,180 \text{ sec}^{-1}$	Independent on C_p
λ_0^-/λ_1^-	0.46 ± 0.04 , present work 0.59 (Ref. 6) 1.14 (Ref. 7)	Dependent on C_p	10.6 ± 1.0 7.8 0
λ_3^-	$\leq 80 \text{ sec}^{-1}$, present work	126 sec^{-1} b)	Independent on C_p

a) Corrected for the redetermination of the $1^- \rightarrow 0^-$ gamma branching ratio (9).

b) See for solution b) in table IV of Ref. 5.

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Figure captions

- Fig. 1 : Gamma-ray spectrum following the capture of muons in H_2O obtained with a 35 cm^3 Ge (Li) detector. The two parts of the spectrum were integrated over slightly different time intervals after the stopping of the muon. The insert shows the relevant level scheme of ^{16}N .
- Fig. 2 : The time dependence, with respect to the muon stop signal, of the photopeak areas due to the 120 keV and 276 keV γ -rays. The heavy curves show the expected time dependences.
- Fig. 3 : The capture rate λ_{0-} and the $\lambda_{0-}/\lambda_{1-}$ ratio calculated by Rho⁵⁾ in the framework of the Migdal theory as a function of C_p , and the corresponding experimental results.

Fig. 1

Fig. 2

Fig. 3