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0^- TO 0^+ BETA DECAY IN A = 16*

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We have completed a measurement of the beta-decay rate of the first excited state of ^{16}N to the ground state of ^{16}O.

$$^{16}N(0^-, 120\ \mathrm{keV}) \longrightarrow {}^{16}O(0^+, 0.00) + e^- + \tilde{\nu}$$

$J^\pi = 0^-$ to 0^+ transitions have been and continue to be of great interest in nuclear physics. They are extremely restrictive as to the form of the one-body operator that can cause the transition. For example, in first order no vector coupling can be responsible. Weak decays between 0^+ and 0^- levels must arise from the axial vector interaction, and further, only two form factors are involved. Realization of this point over a decade ago[1] focussed attention on measuring both muon capture and beta decay rates between such levels to determine the induced pseudoscalar coupling

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in nuclei. The transitions are of interest to nuclear structure studies because they provide a measure of the matrix element of $(\sigma_1 \cdot p_1)$.

Most recently the interest in $0^+ \rightarrow 0^-$ transitions has been rekindled because of the large role expected for pion exchange currents. The significant role that pion exchange currents play in axial vector transitions has been stressed for a long time by M. Erikson,[2] and P. Guichon,[3]. A few years ago a compelling argument indicating where such effects would be most easily observed was made by Kubodera, Delorme and Rho.[4] They argued that transitions depending on the time like component of the axial vector current presented the most favorable case to observe pionic effects. In this case the nucleonic axial current is reduced by a factor of v/c while the pion exchange current is not suppressed. Detailed calculation of this process in A = 16 have recently been carried out by Towner and Kihanna[5] which completely substantiates the points made in Ref. 4. Although there is a theoretical concensus on this issue, precious little supporting experimental data exists.[4]

The capture rate

$$\mu^- + {}^{16}O \longrightarrow {}^{16}N(0^-, 120\ keV) + \nu_\mu$$

has been well studied[6] and the accepted value is $\Lambda_\mu = 1560 \pm 108\ sec^{-1}$. The beta decay of the 0^- level to ^{16}O has been measured[7] only once previously and has a large error. The measurement is difficult owing to the small (order 10^{-6}) branching ratio for beta decay. It is therefore important to confirm the earlier experiment and to reduce the error.

Figure 1 shows all the energy levels[8] involved in the decay. As was recognized by the Louvain group the only characteristic that can be usefully employed to identify the beta rays from the 0^- level is their $7.58 \pm .09\ \mu s$ lifetime. The ^{16}N ground state has a half life of 7.13 sec and must be allowed to decay away in order to avoid a huge background. A moving target to remove the ^{16}N ground state activity in conjunction a pulsed beam are therefore required to do the experiment. The Argonne National Laboratory Dynamitron was used to provide a 30 μA beam of 3.4 – 3.8 MeV D_2^+. The beam was pulsed using an existing electrostatic system. (The ratio of the target current for beam off to beam on was $< 6 \times 10^{-8}$). Figure 2 shows a schematic diagram of the target assembly and reaction chamber. The target was 99% enriched $^{15}NH_4{}^{15}NO_3$ deposited to a thickness of ~ 14 mg/cm^2 into eight 1.6 mm deep grooves in a 3.2 mm thick 50 cm diameter Al disk. The disk was continuously rotated at 3Hz. Data was acquired by pulsing the 30 μA D_2^+ beam on for 10 μs, acquiring data for 60 μ, waiting till the irradiated beam spot moved 1.2 cm and once again pulsing the beam on. After a complete revolution of

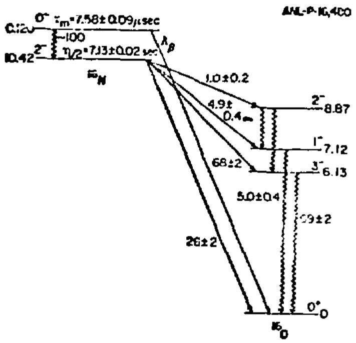

Fig. 1. Relevant levels and transitions in the A = 16 system for ^{16}N beta decay. The branching ratios are percentages and include the effects of cascades.

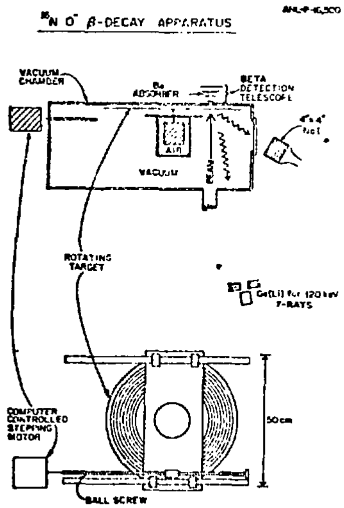

Fig. 2. Diagram of the ^{16}N 0$^-$ beta decay apparatus.

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$6\frac{1}{2}$" x

the wheel a computer controlled stepping motor translated the wheel so that the next groove was bombarded. The complete cycle time for all 8 grooves was set at 17 sec so when a particular segment of target was reused the ^{16}N ground state activity had appreciably decayed. The beam on duty factor was thus 4.6×10^{-4}. The 120 keV photons from the dominant (decay) branch of $^{16}N(0^-)$ were counted in a Ge(Li) detector located ~200 cm from the target. The beta particles were detected in the 4 counter plastic scintillator telescope shown in Fig. 3 in which a valid count required four-fold fast coincidence. The telescope was collimated in order that it view only the activity arising from the previous 10 μs beam pulse. Ground state decays were selected by the use of ^9Be adsorber thickness between the 2nd and 3rd counter. The beam pulsing, data acquisition, and wheel position were all controlled by a dedicated LSI-11 micro computer. A 0^- beta rate of approximately 30/hr was obtained with this system. Figure 4 shows a time spectrum of events from the beta telescope. The 7.58 μs mean life is easily seen.

In order to extract a branching ratio, the absolute efficiency of the beta telescope and gamma ray detector had to be determined. The efficiency of the Ge(Li) detector was easily measured using calibrated gamma ray sources. Fixing the efficiency of the beta detector was more difficult. To do this the absolute efficiency of a 10 cm × 10 cm NaI detector was determined for the ^{16}O(6.13 MeV) gamma rays using the $^{19}F(p,\alpha)^{16}O$ rection on the resonance at E_p = 341 keV. The reaction was observed to be isotropic to 1% and its yield was simultaneously measured with a Si surface barrier detector viewing alpha particles to the 6.13 MeV level of ^{16}O.. Leaving the NaI detector position fixed the 6.13 MeV gamma rays following the decay of the ^{16}N ground state were counted

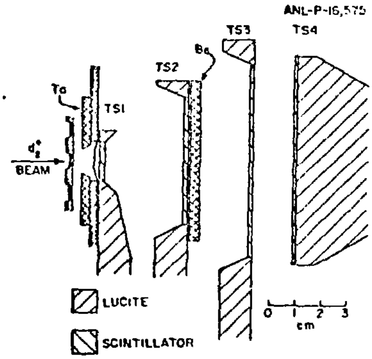

Fig. 3. Diagram of the beta detector telescope.

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while the beta telescope recorded the number of beta decays to the ^{16}O ground state. Since the ratio $\Gamma(2^- \longrightarrow 0^+)/\Gamma(2^- \longrightarrow 3^-)$ for the ^{16}N ground state decay is presently known to only 10.6% (.38 ± .04) the accuracy of the present measurement is thereby limited.

With this procedure we determined the ^{16}N 0^- beta decay branching ratio to be

$$\frac{\Gamma^{0^-}_{0^+}(\beta)}{\Gamma^{0^-}(\text{total})} = (3.13 \pm 0.43) \times 10^{-6}$$

The corresponding transition probability is

$$\Lambda^{\beta} = 0.41 \pm 0.06 \text{ sec}^{-1}$$

This is to be compared to 0.46 ± 0.10 obtained[9] by the Louvain group. They also used the ^{16}N ground state decay to fix their beta detector efficiency. However in their experiment it made a negligible contribution to the final error whereas it is the dominant factor in our more precise measurement. It is gratifying that such good agreement exists between these measurements. Table 1 lists the various sources of error in our result and also indicates the expected improvement in a future experiment. We are also working toward reducing the uncertainty in the $^{16}N(2^-) \xrightarrow{\beta} {}^{16}O(0^+)$ branching ratio.

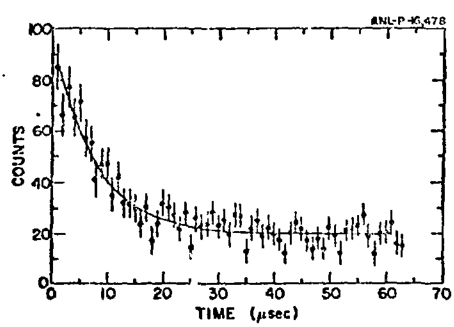

Fig. 4. Observed rate in the beta telescope as a function of time. The curve is a fit of the form $A_{exp}(-t/\tau_m) + C$ with $\tau_m = 7.58$ μs. The background is consistent with the rate expected from ^{16}N (2^-) beta decay.

Using the results from Ref. 5, Fig. 5 compares experiment to the plot of Λ_μ versus Λ_β calculated with a variety of residual interactions and different values of the ratio of the induced pseudoscalar coupling constant (g_p) to the axial vector coupling constant (g_A = 1.25) with and without meson exchange effects. The plot shows that meson exchange currents must be included in order to obtain good agreement with the experimentally observed rates and values for the ratio.. The beta decay is particularly sensitive as it shows a fourfold increase in rate over the values obtained without meson exchange effects. Additional work is worthwhile to verify that the wave functions employed are correct. Improving the experimental values requires that the branching ratio of the ^{16}N ground state to the ^{16}O ground state be determined more precisely.

The $^{16}N(0^-) \rightarrow 0^+$ decay provides an excellent example of how contemporary understanding of nuclear structure extended to include meson exchange currents allows prediction of sensitive axial vector decay rates.. The A = 16 wave functions should provide reliable prediction for the isovector matrix elements of $(\underset{\sim}{\sigma}_i \cdot \underset{\sim}{p}_i)$ involved in nucleon scattering from ^{16}O. We note that to the extent that the (p,n) charge exchange reaction arises from pion exchange there is a formal similarity to the PCAC description of the weak induced pseudo-scalar coupling.

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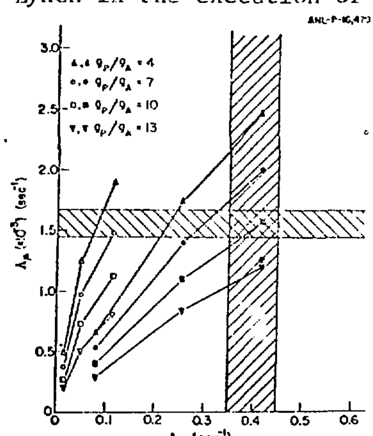

Fig. 5 The measured values of Λ_μ from Ref. 7 and Λ_β from the present work. Also shown as points are calculated values from Ref. 5. The open points are nucleon only impulse approximation while the closed points include the effects of pion exchange currents. The calculations employ three different residual interactions as well as varying values of g_P/g_A.

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Table 1. List of experimental errors in the present and planned $^{16}N(0^-)$ beta decay measurements. The upper case S refer to the error in the calibrated source strength designated by the subscript. Lower case n's refer to yields, and its subscript indicates the radiation type while its superscript refers to the source of the radiation. Unsuperscripted n's are from ^{16}N decays while s and R refer to sources and the $^{19}F(P,\alpha)^{16}O$ reaction, respectively. The ratio $\varepsilon(0^- \rightarrow 0^+)/\varepsilon(2^- - 0^+)$ refers to the uncertainties in the beta spectra shape on the ratio of $0^- \rightarrow 0^+$ beta decays. The T_o entries refer to uncertainties in the counting interval of the beta and gamma detectors.

Quantity	December 81 (act. %)	April 82 Run (est. %)
S_γ	1.9	1.5
S_α	1.0	0.5
$n_\beta(0^- \rightarrow 0^+)$	6.7	~3.0
$n_\gamma(0^- \rightarrow 2^-)$	3.2	<1.0
n_γ^s	2.1	<1.0
$n_\gamma(6.13)$	1.4	<1.0
$n_\beta(2^- \rightarrow 0^+)$	0.5 stat. +3.5 var.	<2.0
n_α^R	1.1	1.0
n_γ^R	1.5	
n_α^s	2.3	0.6
$\frac{\varepsilon(0^- \rightarrow 0^+)}{\varepsilon(2^- \rightarrow 0^+)}$	2.0	2.0
T_o	1.0	0.8
(Total % error)	9.6	4.5