6, 437 (1967) [Sov. J. Nucl. Phys. 6, 318 (1968)].

[4]A. N. Gorbunov, Phys. Lett. 27B, 436 (1968).

[5]R. Mundhenke, R. Kosiek, and G. Kraft, Z. Phys. 216, 232 (1968).

[6]J. Sanada, M. Yamanouchi, N. Sakai, and S. Seki, J. Phys. Soc. Jap. 28, 537 (1970).

[7]Yu, M. Arkatov, P. I. Vatset, V. I. Voloshchuk, V. V. Kirichenko, I. M. Prokhorets, and A. F. Khodyachikh, Pisma Zh. Eksp. Teor. Fiz. 9, 574 (1969) [JETP Lett. 9, 350 (1969)].

[8]J. E. Perry, Jr., and S. J. Bame, Jr., Phys. Rev. 99, 1368 (1955).

[9]C. C. Gardner and J. D. Anderson, Phys. Rev. 125, 626 (1962).

[10]D. S. Gemmel and G. A. Jones, Nucl. Phys. 33, 102 (1962).

[11]G. A. Ferguson, J. Halpern, R. Nathans, and P. F. Yergin, Phys. Rev. 95, 776 (1954).

[12]F. Ferrero, C. Manfredotti, L. Pasqualini, G. Piragino, and P. G. Rama, Nuovo Cimento 45B, 273 (1966).

[13]R. W. Zurmühle, W. E. Stephens, and H. H. Staub, Phys. Rev. 132, 751 (1963).

[14]B. L. Berman, J. T. Caldwell, R. R. Harvey, M. A. Kelly, R. L. Bramblett, and S. C. Fultz, Phys. Rev. 162, 1098 (1967), and references therein.

[15]M. A. Kelly, B. L. Berman, R. L. Bramblett, and S. C. Fultz, Phys. Rev. 179, 1194 (1969).

[16]S. C. Fultz, J. T. Caldwell, B. L. Berman, R. L. Bramblett, and R. R. Harvey, Phys. Rev. 143, 790 (1966).

[17]R. L. Bramblett, J. T. Caldwell, B. L. Berman, R. R. Harvey, and S. C. Fultz, Phys. Rev. 148, 1198 (1966).

[18]F. C. Barker and A. K. Mann, Phil. Mag. 2, 5 (1957).

[19]E. M. Henley, in *Isospin in Nuclear Physics,* edited by D. H. Wilkinson (North-Holland, Amsterdam, 1969), p. 43.

[20]We are indebted to Dr. F. W. K. Firk for this remark.

[21]W. E. Meyerhof and T. A. Tombrello, Nucl. Phys. A109, 1 (1968).

EVIDENCE FOR PARITY-FORBIDDEN α-PARTICLE DECAY FROM THE 8.87-MeV 2^- STATE IN ^{16}O

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The energy spectrum of 1.3×10^8 α particles from the sequential decay $^{16}N(\beta^-)^{16}O(\alpha)^{12}C$ has been obtained. A group of 7100 ± 1800 α particles with an energy of 1278 ± 10 keV has been identified. They are attributed to the parity-forbidden decay from the ^{16}O 8.87-MeV 2^- state into $^{12}C + \alpha$. A width $\Gamma_\alpha = (1.8 \pm 0.8) \times 10^{-10}$ eV has been obtained for this transition.

A search for α-particle decay from unnatural-parity states in even-even nuclei provides a direct test of parity mixing in nuclear energy levels.[1] The 8.87-MeV 2^- state in ^{16}O offers the most favorable conditions for such a test. The excitation energy of this level exceeds the binding energy of an α particle in ^{16}O by 1.71 MeV. It can be populated from the β^- decay of ^{16}N ($T_{1/2} = 7.1$ sec). A fraction (1.1%) of the betas from ^{16}N goes into the 8.87-MeV state, which in turn is de-excited by γ-ray cascades to the ^{16}O ground state. The beta branching ratio to the neighboring 9.61-MeV 1^- level is only 1.2×10^{-3}%. Beta transitions to this state give rise to a broad α-particle distribution from the parity-allowed decay into $^{12}C + \alpha$. Superimposed on this distribution, a group of α particles with an energy[2] of 1280 ± 2 keV should appear in the case of the parity-forbidden decay from the 8.87-MeV state. The first attempts to observe this unusual decay were undertaken independently by several groups[3-6] nearly ten years ago. Low intensity and insufficient energy resolution restricted their results to an upper limit, $\Gamma_\alpha \leqslant (3\text{-}6) \times 10^{-9}$ eV, for the width of the parity-forbidden α-particle decay of the 8.87-MeV state. Recently,[7] this upper limit has been reduced to $\Gamma_\alpha \leqslant 1.6 \times 10^{-9}$ eV.

^{16}N was produced by the reaction $^{15}N(d, p)$, bombarding 96%-enriched ^{15}N gas at atmospheric pressure with 3-MeV deuterons. The irradiated gas was allowed to flow from the target vessel through a thin capillary into a small detection chamber (2 cm^3 volume). The gas pressure within this chamber was kept at 7 ± 1 Torr. α-particles leaving the chamber through four circular windows (8 mm diam), consisting of 30-μg/cm^2-thick collodion foils, were detected by four Ortec A-018-025-100 surface-barrier detectors. The pulses from the detectors, after appropriate amplification, entered a 4×128-channel Laben pulse-height analyzer. From repeated calibrations, the energy of the α particles was determined with a precision of ±10 keV. A detailed description of the experimental arrangement has been given elsewhere.[8]

Figure 1 shows the pulse-height distribution of

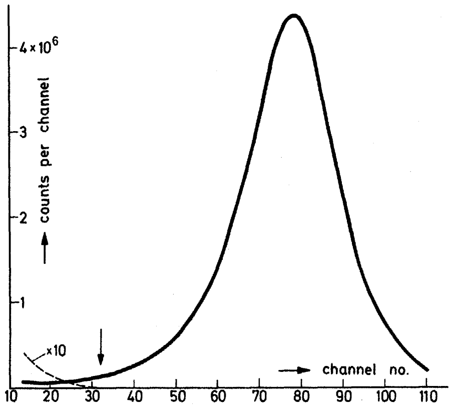

FIG. 1. Pulse-height distribution of 1.3×10^8 α particles as given by an IBM plotter. The arrow indicates the position of the parity-forbidden α-particle group. The dashed curve shows the background on a tenfold enlarged scale.

1.3×10^8 α particles. The arrow above channel 32 marks the position (1280 keV) where the parity-forbidden α-particle group is expected. The dashed curve in Fig. 1 represents the background on a tenfold enlarged scale. This background is mainly due to the electrons from the ^{16}N beta decay and was measured by placing aluminum foils (5 mg/cm^2) between the collodion windows and the detectors. The absorber prevented α particles with energies below 5 MeV from reaching the counters, whereas it had little effect on the beta spectrum. The total background amounts to 50% of the counting rate for channel 13 and less than 2% for channel 32. After subtraction of the background, the remaining pulse-height distribution from channel 13 to channel 53, with the exception of the five channels 30-34, can be approximated by an exponential function (see Fig. 2). The deviations of the measured points from this exponential function are displayed in Fig. 3.

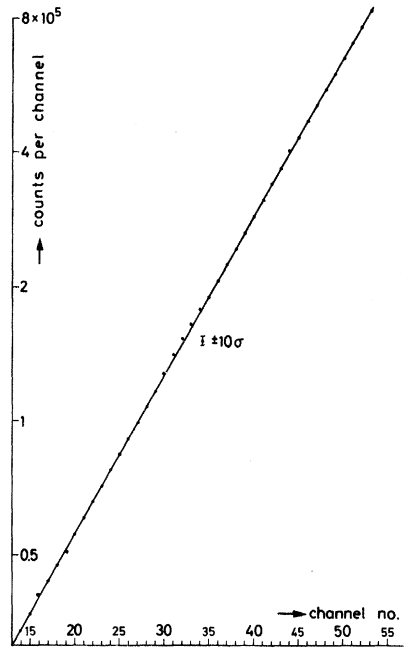

FIG. 2. Pulse-height distribution of 41 channels (13-53) on a logarithmic scale (background subtracted). The error bar indicates the tenfold mean statistical error.

The analysis of the experimental data was performed in the following manner. The measured pulse height distribution, before background subtraction, contained in the interval of channels 13-53 was least-squares fitted by the expression

$$W(x)=A\exp(-\alpha x)+B\exp(\beta x)+C,$$

where x is the channel number. The five parameters A, α, B, β, and C were determined by the fit. A χ^2 test of this fit results in the value $\chi_n^2=51$ ($n=35$) which corresponds to a probability $P(\chi^2>\chi_n^2)<4\%$. Since the five channels 30-34 contribute ~12 to the value of χ_n^2, they were omitted and a second least-squares fit performed with the remaining 36 channels. The second fit resulted in $\chi_n^2=31$ ($n=30$) and $P(\chi^2>\chi_n^2)=40\%$. From this result, the positive excess due to the five channels 30-34 (see Fig. 3) must be taken as

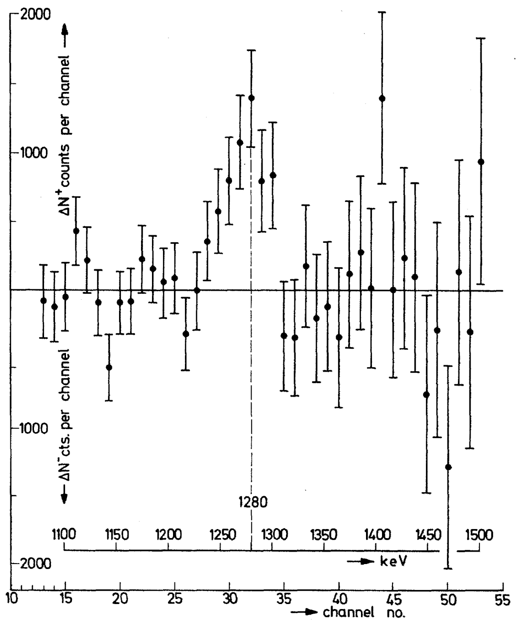

FIG. 3. Deviations of the pulse-height distribution, displayed in Fig. 2, from the approximating exponential function ($=\Delta N^{\pm}$). The error bars indicate the mean statistical error of the measured points.

statistically significant. In order to take into account the influence of these five channels properly, a Gaussian function was superimposed on the smooth function $W(x)$ and the resulting expression $W(x)+D\exp[-4\ln 2(x_0-x)^2/H^2]$ was fitted to the experimental pulse-height distribution. In this case, the six parameters A, α, B, β, C, and D were now determined by the fit. The width H (full-width at half-maximum) of the Gaussian was taken to be 5 channels (53 keV) in accordance with the response function of the detecting system for monoenergetic α particles (see Ref. 3). Fits were performed with different values of x_0 between 30 and 34. The best fit $[\chi_n^2=31$ $(n=34)$, $P(\chi^2>\chi_n^2)=62\,\%]$ was obtained with $x_0=31.5$ $(E_\alpha=1275$ keV). The maximum value of the Gaussian was found to be $D=1190\pm 300$. (The error indicated for D is the variance of this parameter, calculated by the Gaussian method of least squares.)

In order to check to what extent this result depends on the special form chosen for the regression curve $W(x)$, a second fit to the experimental pulse-height distribution was performed using polynomials, $P_m(x)$, of degree $m=4, \cdots, 8$. Again, a Gaussian was superimposed and the expression $P_m(x)+D\exp[-4\ln 2(x_0-x)^2/H^2]$ was least-squares fitted to the experimental values. The best fit $[\chi_n^2=30$ $(n=32)$, $P(\chi^2>\chi_n^2)=56\,\%]$ was obtained for $m=6$ and $x_0=32$ $(E=1280$ keV) with $D=1470\pm 380$. Taking the average of the values of D and x_0 resulting from the two different regression curves, one obtains for the area under the Gaussian $N_\alpha(8.87)=(\pi/\ln 2)^{1/2}DH/2=7100\pm 1800$. This value is taken as the number of α particles belonging to a group with energy 1278 ± 10 keV and attributed to the parity-forbidden α disintegration from the 8.87-MeV 2^- state in ^{16}O. For the ratio of this number ot the number of beta transitions from ^{16}N, leading to the 8.87-MeV state, one has the relation

$$\frac{N_\alpha(8.87)}{N_\beta(8.87)}=\frac{\Gamma_\alpha}{(\Gamma_\alpha+\sum\Gamma_{\rm rad})}\simeq\frac{\Gamma_\alpha}{\sum\Gamma_{\rm rad}},$$

where $\sum\Gamma_{\rm rad}$ is the total radiation width of the 8.87-MeV state. $N_\beta(8.87)$ is related to $N_\alpha(9.61)$, the number of α particles originating from the ^{16}O 9.61-MeV 1^- state, by the β-decay branching Y:

$$Y(8.87)/Y(9.61)=N_\beta(8.87)/N_\alpha(9.61).$$

With $Y(8.87)=(1.0\pm 0.2)\times 10^{-2}$,[8] $N_\alpha(9.61)=1.3\times 10^8$, $Y(9.61)=(1.19\pm 0.10)\times 10^{-5}$,[9] and $\sum\Gamma_{\rm rad}=2.7\pm 0.5$ meV,[10] one finally obtains the width for the parity-forbidden α particle transition,

$$\Gamma_\alpha=\frac{N_\alpha(8.87)}{N_\alpha(9.61)}\frac{Y(9.61)}{Y(8.87)}\sum\Gamma_{\rm rad}=(1.8\pm 0.8)\times 10^{-10}\ \text{eV}.$$

In a previous paper (see Ref. 8) an upper limit of 0.94×10^{-10} eV (i.e., much less than the actual value presented here) has been given for Γ_α. This quantity has been determined in the usual way, by taking 3 times the square root of the number of α particles contained in the channels 30-34. We believe now that this procedure is not applicable in the present case, where an energy spectrum of unknown shape has to be analyzed. The smallest positive excess recognizable by the method of least-squares fitting will always be greater than the upper limit determined by the square-root rule.

Our numerical value for Γ_α is in rough agreement with the theoretical calculations of Gari and Kümmel[11,12] and of Henley, Keliher, and Yu.[13] Since this parity-forbidden transition must be ascribed to an isospin $\Delta I=0$ parity-nonconserving nucleon-nucleon force, the result of this experiment strongly supports the existence of strangeness-nonchanging currents mediating the weak interaction in the current-current form.

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[1] D. H. Wilkinson, Phys. Rev. 109, 1603 (1958). For a comprehensive survey, see also E. M. Henley, Annu. Rev. Nucl. Sci. 19, 367 (1969).

[2] C. P. Browne and I. Michael, Phys. Rev. 134, B133 (1964).

[3] R. E. Segel, J. W. Olness, and E. L. Sprenkel, Phil. Mag. 6, 163 (1961).

[4] D. E. Alburger, R. E. Pixley, D. H. Wilkinson, and P. Donovan, Phil. Mag. 6, 171 (1961).

[5] W. Kaufmann and H. Wäffler, Nucl. Phys. 24, 62 (1961).

[6] R. E. Segel, J. W. Olness, and E. L. Sprenkel, Phys. Rev. 123, 1382 (1961).

[7] D. P. Boyd, P. F. Donovan, B. Marsh, D. E. Alburger, D. H. Wilkinson, P. Assimakopoulos, and E. Beardsworth, Bull. Amer. Phys. Soc. 13, 1424 (1968).

[8] H. Hättig, K. Hünchen, P. Roth, and H. Wäffler, Nucl. Phys. A137, 144 (1969).

[9] D. E. Alburger, A. Gallmann, and D. H. Wilkinson, Phys. Rev. 116, 939 (1959).

[10] M. C. Bertin and R. E. Pixley, Nucl. Phys. A150, 247 (1970)

[11] M. Gari and H. Kümmel, Phys. Rev. Lett. 23, 26 (1969).

[12] M. Gari, Phys. Lett. 31B, 627 (1970).

[13] E. M. Henley, T. E. Keliher, and D. U. L. Yu, Phys. Rev. Lett. 23, 941 (1969).