PHYSICAL REVIEW C VOLUME 13, NUMBER 6 JUNE 1976

Beta-ray branching in the decay of ^{19}Ne†

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(Received 22 December 1975)

The β decay of ^{19}Ne has been studied by measuring the γ-ray spectrum with a Ge(Li) detector. Sources were made in the $^{19}F(p,n)^{19}Ne$ reaction by 7.0-MeV proton bombardment of CaF_2 or BaF_2 targets mounted in a graphite "rabbit." From the intensity of a weak 1357-keV peak relative to 511-keV γ rays the β^+ branching of ^{19}Ne to the 1554-keV state of ^{19}O was found to be $(2.1 \pm 0.3) \times 10^{-5}$ per decay. This is a factor of 2.6 larger than a recently reported value but does not substantially improve the prospects for an experiment designed to study neutral currents in weak interactions.

[RADIOACTIVITY ^{19}Ne: measured I_γ; deduced β^+ branch, logft value.]

There have been two recent measurements[1,2] on the β decay of ^{19}Ne related to a proposed experiment[3] designed to study the presence of neutral currents in weak interactions. The expected yield in the proposed experiment, involving the detection of inelastic neutrino scattering on ^{19}F to its 1554-keV excited state, depends on the value of the β^+ branching of ^{19}Ne to this state. Mann and Kavanagh[1] obtained an upper limit of 3×10^{-5} per decay for this branch of ^{19}Ne by searching for 1357-keV γ rays; the 1554-keV state is known[4] to decay 92.5% via a cascade to the ^{19}F 197-keV state.

In an effort to enhance the sensitivity for seeing the 1357-keV γ ray by reducing the underlying background of annihilation-in-flight radiation due to the ^{19}Ne positrons, a continuum spectrum extending up to 2.2 MeV, Freedman, Del Vecchio, and Callias[2] designed a detection chamber which allowed a large fraction of the positrons to leave the thin-walled source cell and annihilate in regions shielded from their Ge(Li) detector. They observed a 1357-keV peak having a net amplitude ~40% as large as the underlying background. From the intensity of this γ-ray they deduced a ^{19}Ne β-ray branch of $(8.2 \pm 2.0) \times 10^{-6}$ to the 1554-keV state.

Several difficulties in the experiment of Freedman *et al.* were discussed by the authors. It had been pointed out by R. W. Kavanagh that the 12-MeV protons used to form the ^{19}Ne gas samples in the $^{19}F(p,n)$ ^{19}Ne reaction would result in the production of some ^{19}O via the secondary $^{19}F(n,p)^{19}O$ reaction in the target cell. The threshold for the latter reaction is at $E_n = 4.26$ MeV, whereas the neutrons from the $^{19}F(p,n)^{19}Ne$ reaction at $E_p = 12$ MeV can be as high as 7.96 MeV. Even a small amount of ^{19}O would be troublesome because of its 58% β-ray branch[4] to the 1554-keV state of ^{19}F. There would obviously be great difficulty in trying to establish whether the observed 1357-keV γ ray decays with the 17.36 ± 0.06-sec half-life[5] of ^{19}Ne or with the 27.1 ± 0.1-sec half-life[6] of ^{19}O. It was argued by Freedman *et al.* that only a small amount of ^{19}O was being produced and very little of it would be able to pass through the trapping system to the counting cell, although no experimental tests of that assumption were made.

The other difficulty in the experiment of Freedman *et al.* was that of normalizing the intensity of the observed 1357-keV γ rays to the total number of ^{19}Ne disintegrations. Two normalizing procedures were described. In the more usual measurement of a positron branching ratio to a γ-ray emitting state precautions are taken to cause close to 100% of the positrons to be absorbed and annihilate in the immediate vicinity of the source. Then one needs to determine only the relative intensities of the annihilation radiation and the γ ray from the state in question to obtain the branching ratio.

The present experiment on ^{19}Ne was designed to overcome both of the above mentioned uncertainties in the results of Freedman *et al.* To ensure that ^{19}O could not be produced in the $^{19}F(n,p)^{19}O$ reaction from neutrons following the $^{19}F(p,n)^{19}Ne$ reaction a proton beam energy of 7.0 MeV was used from one of the MP tandem Van de Graaff accelerators. The Q value for the $^{19}F(p,n)^{19}Ne$ reaction is -4.02 MeV, and thus at $E_p = 7.0$ MeV the maximum neutron energy is 2.93 MeV which is well below the threshold of 4.26 MeV for forming ^{19}O via the (n,p) reaction. Neutrons from various common target contaminants such as ^{13}C are similarly all too low in energy to make ^{19}O (for example, at $E_p = 7.0$ MeV the neutrons from $^{13}C(p,n)^{13}N$ have $E_{max} = 3.96$ MeV). The only other way that ^{19}O could be made is via the $^{18}O(n,\gamma)^{19}O$

reaction. In some initial tests the target "rabbit" was made of Delrin which contains ~ 50% oxygen by weight. The presence of neutrons in the target room might have given rise to some ^{19}O in the Delrin due to the 0.2% ^{18}O isotope of oxygen. Although there was no clear evidence for the production of ^{19}O in the Delrin the targets were thereafter mounted in a rabbit made from reactor grade graphite which was propelled back and forth with helium gas. As far as can be determined all possibilities for making ^{19}O in the target-rabbit assembly have been eliminated.

Targets consisted of either crystalline CaF_2 or BaF_2 powder compressed into a hard pellet. These samples were held by friction fits in a well in the graphite rabbit. At $E_p = 7.0$ MeV on the CaF_2 target some weak activities in addition to the ^{19}Ne were observed such as ^{44}Sc from (p,n) reactions on calcium isotopes, but for the BaF_2 target the ^{19}Ne activity was very pure, as had already been observed[5] in half-life measurements under similar conditions. In order to make the activity a gate valve was opened to allow the beam to pass directly onto the target. The alternative arrangement of using a thin Ni foil to separate the rabbit line from the accelerator vacuum system (in which case the gate valve is left open) was not used for fear of either neutron production from Ni isotopes, or deposition of activities from the foil onto the target.

At the detector end of the rabbit line an 8-cm long by 1-cm thick graphite collar, centered on the stopped position of the rabbit, completely surrounded the transfer tubing in order to absorb emerging positrons. The dimensions of the rabbit itself prevented any positrons from escaping in either direction through the interior of the transfer tubing. As discussed above these precautions permit the straightforward normalization of γ-ray intensities thereby overcoming the other uncertainty in the experiment of Freedman *et al.*[2] A Pb absorber 2.54 cm thick was placed between the graphite collar and the Ge(Li) detector. Consideration of the γ-ray absorption coefficients in Pb and graphite shows that this arrangement favors the transmission of 1357-keV γ rays by a factor of 16 relative to the 511-keV radiation. A correspondingly higher counting rate in the region of the1357-keV peak can therefore be achieved for a given total counting rate since the total rate is determined almost entirely by the 511-keV radiation. This feature is important inasmuch as the 1357-keV peak is expected to be weak compared with the background requiring good statistics for definition.

The experimental procedure consisted of repeatedly bombarding the target with a 7.0-MeV proton beam of ~ 100 nA for 5–8 sec, transferring the rabbit to the detector, and counting for 15 sec, all functions being controlled by a timer-programmer unit. The beam intensity and timing were adjusted so that the initial total counting rate was ~ 6000/sec which was consistent with obtaining good statistics without degrading the detector resolution. A weak source of ^{60}Co was located so as to add calibration peaks to the spectrum.

Figure 1 shows a portion of one of the spectra obtained in the vicinity of the ^{60}Co 1332.5-keV peak and the 1357-keV line of ^{19}Ne. The energy of the latter, based on the calibration taken from the ^{60}Co peaks, is 1356.92± 0.15 keV in good agreement with the value of 1357.0± 0.2 keV derived from the 1554.1± 0.2- and 197.15± 0.01-keV energies[4] of the two ^{19}F states.

The efficiency versus γ-ray energy of the Ge(Li) detector was established with sources of ^{22}Na and ^{56}Co. A computer fit to the ^{19}Ne data was made in the region of the 1357-keV line, as shown by the solid line in Fig. 1, using the ^{60}Co line shape and a quadratic background function. After finding the net areas under the 1357- and 511-keV peaks the ^{19}Ne β^+ branching ratio was calculated using the detector efficiency function and correcting for the absorption of γ rays in the graphite collar and in the Pb, as well as for the two annihilation quanta per decay. Corrections were also made to the 511-keV peak intensity for the 5% of positrons that annihilate in flight and to the 1357-keV line for the 92.5% γ-ray branching ratio of the 1554-keV state. Based on the two best results (one with the CaF_2 target and the other with BaF_2) of four separate experiments the ^{19}Ne β^+ branch to the 1554-keV state of ^{19}F was found to be $(2.1 \pm 0.3) \times 10^{-5}$. This

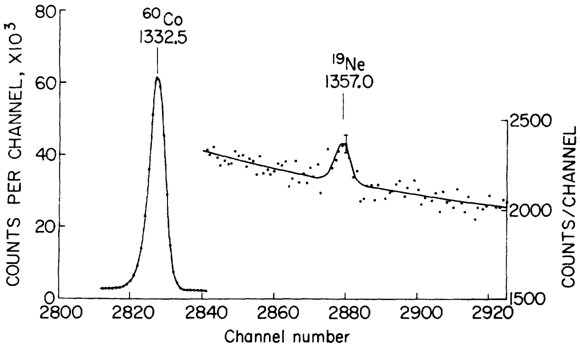

FIG. 1. Portion of the γ-ray spectrum from the decay of ^{19}Ne taken with a 50-cm^3 high-resolution Ge(Li) detector in a 16-h run. The region includes the 1357-keV peak of ^{19}Ne following the β^+ branch to the ^{19}F 1554-keV state, the 1332.5-keV line from a ^{60}Co calibration source, and an underlying background of annihilation-in-flight radiation due to the ^{19}Ne positrons. The solid line in the region of the 1357-keV peak is a computer fit to the data. Areas under the 511- and 1357-keV peaks were 1.83 $\times 10^7$ and 1160 ± 128 counts, respectively.

result is consistent with the upper limit of 3×10^{-5} determined by Mann and Kavanagh[1] but is a factor of 2.6 larger than the branch derived by Freedman *et al.*[2]

The fact that the same β-ray branching ratio, within errors, was obtained with two different fluorine target compounds argues in favor of the assignment of the observed 1357-keV peak to ^{19}Ne decay. Positive proof of this assignment could be made by a half-life determination. An estimate of this possibility under the experimental conditions used for the data of Fig. 1 can be made by supposing that the γ-ray spectrum following each irradiation is stored in two successive 17-sec time bins. In order to show that the 1357-keV peak decays with the ^{19}Ne half-life, excluding the ^{19}O half-life by 3 standard deviations, the total data taking time would have to be about 120 hours. This test has not been attempted.

Log*ft* values were obtained from a desk calculator program.[7] For the ^{19}Ne branches to the ground and 1554-keV states of ^{19}F the log*ft* values are 3.237 ± 0.001 and 5.72 ± 0.06, respectively. The present result for the branch to the 1554-keV state would imply that the counting rate in the neutrino inelastic scattering experiment proposed by Donnelly *et al.*[3] would be only 0.15 counts per day.

The author would like to thank D. H. Wilkinson for suggesting this measurement.

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†Research carried out under the auspices of the U. S. Energy Research and Development Administration.

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