Communications

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Measurement of the branching ratio for the β decay of ^{19}Ne to the 1554 keV state in ^{19}F and its implications for a study of the neutral weak current*

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The branching ratio $[^{19}\mathrm{Ne} \rightarrow {}^{19}\mathrm{F}^*(1554\ \mathrm{keV}) + e^+ + \nu]/[^{19}\mathrm{Ne} \rightarrow {}^{19}\mathrm{F} + e^+ + \nu]$ as inferred from observing a subsequent γ transition in ^{19}F is found to be $(8.2 \pm 2.0) \times 10^{-6}$. Uncertainties about possible ^{19}O contamination lead to the conservative interpretation of this result as an upper limit for the branching ratio. The implications for a recently suggested study of inelastic neutrino scattering from ^{19}F are discussed.

[RADIOACTIVITY ^{19}Ne; measured β decay branching ratio to 1554 keV level.]

The mounting evidence from high energy neutrino-nucleon scattering experiments[1] for the presence of a neutral current in the semileptonic weak interaction has lead to considerations of the implications for phenomena at lower energies. In particular, it has been noted that neutrino-nucleus scattering, both elastic[2] and inelastic,[3] could provide valuable confirmation of the existence of a neutral weak current and may become a useful tool for studying its structure.

Donnelly *et al.*[3] have outlined several examples of neutrino-nucleus inelastic scattering experiments in which the reaction is observed by detecting the radiative decay of the neutrino excited target nucleus. One of their examples is the reaction $^{19}\mathrm{F}(\bar{\nu}_e, \bar{\nu}_e')^{19}\mathrm{F}^*$ (1554 keV) which can be identified by coincidence detection of a 1357 and a 197 keV γ ray cascading from the 1554 keV level. The production cross section for reactor neutrinos is predicted to be $6.3 \times 10^{-44} B$ cm^2/nucleon $\bar{\nu}_e$, where B is the branching ratio for the decay of ^{19}Ne to the 1554 keV level in ^{19}F relative to the ground state to ground state β decay. The prediction is based on Weinberg's form for the neutral current, the allowed approximation, and the assumption that relevant levels are pure states of isospin. To the extent that isospin mixing can be neglected, a measurement of B provides a prediction for the production cross section that is independent of nuclear models.

In order to estimate the count rate for the proposed experiment, Donnelly *et al.* calculated B using the single particle Nilsson model, obtaining $B = (1.0 \pm 0.9) \times 10^{-4}$. For their scheme, a hexagonal array of 300 $\mathrm{BaF_2}$(Eu) detectors and the neutrino flux from the Savannah River reactor, they predict 0.7 γ coincidences/day with an equal background rate. Lanford and Wildenthal,[4] however, obtained a much smaller value ($B = 3 \times 10^{-10}$) on the basis of the multiparticle shell model indicating a correspondingly smaller count rate. We have also run the shell model calculation using the Oak Ridge-Rochester shell model code[5] and while our result[6] ($B = 1.5 \times 10^{-7}$) disagrees with Wildenthal's, it also indicates that the proposed experiment is unfeasible because the count rate would be unreasonably small.

Recently Mann and Kavanagh[7] placed an experimental upper limit on B ($B < 3 \times 10^{-5}$) suggesting that the count rate in the proposed experiment will be less than 0.2/day and the signal-to-noise ratio will be less than 0.3. In order to better assess the feasibility of the experiment by Donnelly *et al.* we have also attempted to measure B.

A gaseous sample of ^{19}Ne was produced by the $^{19}\mathrm{F}(p,n)^{19}\mathrm{Ne}$ reaction using a target of $\mathrm{SF_6}$ gas at

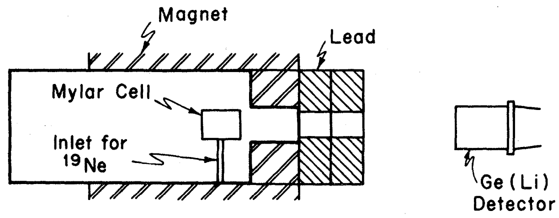

FIG. 1. Schematic of the ^{19}Ne source and detector geometry. A second call and detector (not shown) were used for normalization.

0.7 atm and a 12 MeV (15 μA) proton beam from the Princeton cyclotron. The target was a cylinder 2.5 cm diam and 38 cm long having a 0.13 mm aluminum entrance window; a nickel plug stopped the beam. Gas from the target passed through a liquid nitrogen trap which condensed the SF_6 but not the ^{19}Ne. Gas from the nitrogen trap entered a chamber containing another liquid nitrogen trap and a 40°K trap (the temperature was maintained with a Displex helium refrigerator). Radioactive gas from the chamber diffused into a cylindrical thin walled Mylar cell (4.5 cm diam by 6 cm long) enclosed in an evacuated aluminum chamber as shown in Fig. 1. A 40 cm^3 Ge(Li) detector shielded with lead viewed the cell through a 4.5 cm diam hole in a lead collimator. We observed the 1357 keV γ ray (93% branch) from the decay of the 1554 keV level to the excited $\frac{5}{2}^+$ state at 197 keV.

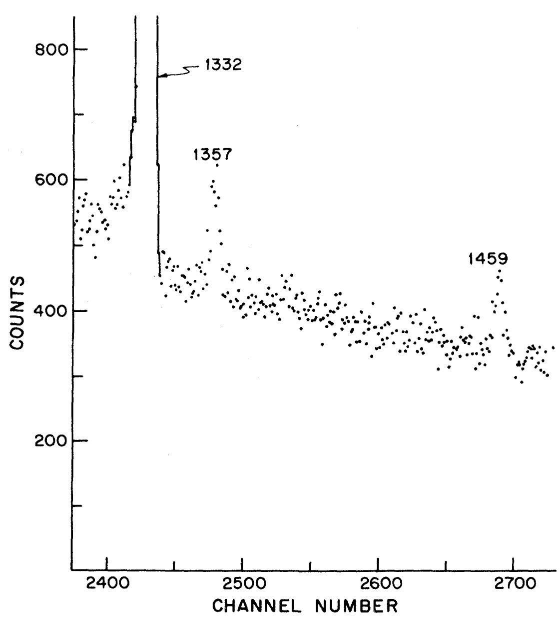

FIG. 2. γ ray spectrum from ^{19}Ne β decay. The peak at 1332 keV is from a ^{60}Co calibration source and the peak at 1459 keV is from ^{40}K contamination in the lead shielding.

The experiment is designed to reduce the background at 1357 keV due to positron annihilation in flight. Positrons from ^{19}Ne decay pass through the Mylar cell walls and annihilate on the walls of the vacuum chamber. Only a relatively small area of the chamber is visible to the detector, however, and the effective solid angle for detection of annihilation radiation is an order of magnitude less than the solid angle for detecting direct radiation from the cell. As a further precaution against annihilation in flight radiation, the cell and vacuum chamber were placed in the gap of a magnet which could produce a ~3 kG field perpendicular to the Mylar cell-detector line of sight. With the magnetic field turned on, positrons were deflected from striking the front [Ge(Li) side] of the chamber and hence did not contribute to annihilation in flight radiation having energy in the region of interest. This provided another factor of 4 reduction in background, but since a clear signal could be seen without using the magnet it was turned off for the final runs in order to facilitate a simple Monte Carlo analysis of the results.

Figure 2 shows a typical γ spectrum in the region of the 1357 keV γ ray. The large peak to the left of 1357 keV is the 1332 keV line from a ^{60}Co calibration source and the smaller peak to the right is the 1459 keV line from ^{40}K contamination on the lead bricks. Runs with the gas flow cut off at the cell verified that the peak at 1357 was not due to background from outside the cell.

Two procedures were used to normalize the intensity of the 1357 keV γ ray to the total decay rate. A Monte Carlo calculation determined the relative geometric detection efficiency for 511 annihilation radiation and direct radiation from the cell and was used to correct the observed ratio of 1357 to 511 keV counts. The second procedure involved the use of a second decay cell run in parallel with the first. The second cell had thick walls (two cells were tried, one constructed of Lucite and the other brass) so that all positrons annihilated in the cell. A 32 cm^2 Ge(Li) detector viewed the second cell. The efficiency of the two detectors for 511 keV γ rays relative to each other was measured using a ^{22}Na source surrounded by brass absorbers. For each detector the source was placed at the respective cell location, several measurements were made at slightly different distances, and a Monte Carlo calculation was used to obtain the detector efficiency averaged over the finite size of the relevant cell. The relative efficiency of the 32 cm^3 Ge(Li) for 511 keV γ rays and the 40 cm^3 Ge(Li) for 1357 keV γ rays was then obtained using a calibration curve for the 40 cm^3 Ge(Li) measured with calibrated ^{22}Na and ^{60}Co sources. Precautions were taken to insure that the gas pressures in the two cells were the same during the experiment and after corrections for the relative volumes of the cells, the 511 rate in the 32 cm^3 Ge(Li) was used to indicate the total decay rate in the Mylar cell.

The final results contain corrections for attenuation of γ rays, corrections to the 511 photopeak area due to annihilation in flight,[8] corrections due to finite cell volumes, and a correction for the 93% branching ratio for decay of the 1554 keV level by the relevant mode. Using the second cell and detector to normalize we obtain $B=(8.2\pm2.0)\times10^{-6}$ (this represents the combined and consistent results of runs with a Lucite and a brass normalization cell). The Monte Carlo normalization procedure gave $B=(6.4\pm0.7)\times10^{-6}$, where the error is purely statistical. Since the Monte Carlo calculation did not include the effects of positron backscattering, however, we feel it is less reliable. About half of the stated error is due to statistics; the rest reflects estimates of systematic errors in the normalization procedure, the detector calibrations, and the other corrections.

A possible source of systematic error is the presence of ^{19}O. ^{19}O is produced in the target via the reaction ^{19}F$(n,p)^{19}$O with energetic neutrons from the primary reaction. If ^{19}O were transported to the decay cell it would have produced 1357 keV γ rays since its dominant β decay mode (58% branch) is to the 1554 keV level in ^{19}F. We estimate that the ratio of ^{19}O to ^{19}Ne produced in the target was $\sim5\times10^{-5}$; the half-life of ^{19}O (29 sec) is comparable to ^{19}Ne (17 sec). It should be noted that the ^{19}O would be produced as atomic oxygen and, while it is unlikely that it would react with SF_6, it is quite likely that it would adsorb to the walls of the vacuum system. Even if atomic ^{19}O reacted to form a gaseous molecule this would likely be removed by one of the cold traps. Nevertheless, we are not able to conclusively eliminate the possibility that part of our signal was due to ^{19}O contamination. A conservative interpretation of our result based on this possibility is that it represents an upper limit for the branching ratio of ^{19}Ne. With a branching ratio $B=(8.2\pm2.0)\times10^{-6}$ the expected rate for the experiment of Donnelly *et al.* is 0.06 γ coincidences/day with a signal-to-noise ratio of 0.08. This rate is an upper limit if B is interpreted as an upper limit.

Our result is consistent with the limit obtained by Mann and Kavanagh; it is not, however, conclusively in disagreement with the small values predicted by recent shell model calculations.

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[4]The calculated logft (logft = 10.5) is reported by W. A. Lanford and B. H. Wildenthal, Phys. Rev. C 7, 668 (1973).

[5]J. B. French, E. C. Halbert, J. B. McGrory, and S. S. M. Wong, *Advances in Nuclear Physics*, edited by M. Baranger and E. Vogt (Plenum, New York, 1969), Vol. 3.

[6]The calculated logft is 7.8.

[7]F. M. Mann and R. W. Kavanagh, Phys. Lett. 51B, 49 (1974).

[8]The annihilation in flight corrections for various materials were made using the results of J. Kantele and M. Valkonen, Nucl. Instrum. Methods 112, 501 (1973).