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Search for Two-Photon Decay in Thermal *np* Capture

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An upper limit of 10^{-4} has been obtained for the branching ratio for the emission of two photons ($E_\gamma > 0.57$ MeV) following thermal neutron capture in hydrogen. This limit was obtained with two Ge(Li) detectors shielded so as to reduce γ-ray scattering from one detector into the other and is a factor of 10 lower than has been recently reported.

A recent publication[1] reported a branching ratio of 10^{-3} for two-photon decay following *np* radiative capture. This ratio is at least a factor of 200 higher than current theoretical estimates.[2] We have searched for this decay mode with Ge(Li) detectors in a configuration that reduced γ-ray scattering from one detector into the other and have obtained an upper limit for this branching ratio of 10^{-4}.

The present experiment was performed with 0.025-eV neutrons obtained by Bragg reflecting a beam of neutrons from the NRU reactor thermal column with a Ge monochromator. The beam traveled down a flight tube lined with 5 mm of ^{6}LiF to a distilled H_2O sample contained in a thin-walled Lucite cylinder (4.1 cm× 4.2 cm long). The ^{6}LiF shielded the detectors from neutrons in the beam and from neutrons scattered by the sample. Two Ge(Li) detectors having photopeak efficiencies of 11.3 and 6.7% (relative to a 3-in. × 3-in. NaI detector at 25 cm) were placed as close to the target as possible. These detectors were shielded such that the counting rate of 2.223-MeV γ rays with the H_2O sample removed was less than 10^{-4} of the counting rate with it in place.

The linear signals from the Ge(Li) detectors were summed and gated by pulses from a standard fast-slow coincidence circuit before analysis. The fast-coincidence time resolution was 5.7 nsec full width at half-maximum and thresholds associated with the slow-coincidence circuit required the γ-ray energy deposited in each detector to be >0.57 MeV. This energy discrimination was selected to reject singly Compton-scattered γ rays and positron-annihilation photons that crossed from one detector to the other.

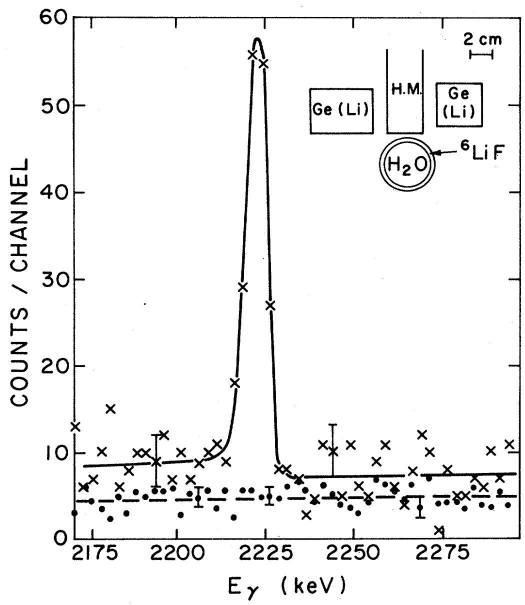

FIG. 1. Sum spectra from $^1H(n,\gamma)^2H$ coincidences obtained with two Ge(Li) detectors in the geometry shown in the inset. Solid curve (crosses) is without the H.M. (heavy metal) shield, and dashed curve (circles) is with the shield in place. The spectra are normalized to the same neutron fluence and required 3 days of running time to collect.

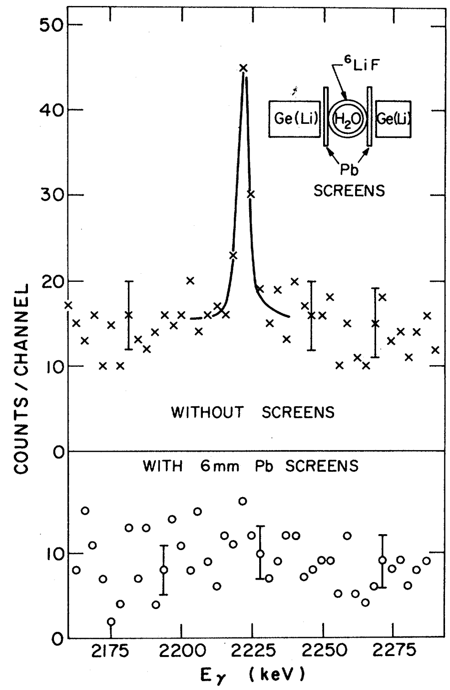

FIG. 2. Sum spectra at 180° with and without Pb screens between the sample and detectors, normalized to the same neutron fluence.

The coincidence efficiency of each detector-target configuration was measured by using the 1.17- and 1.33-MeV coincident γ rays from a ^{60}Co source dissolved in a water medium similar in dimensions to the target.

The crosses in Fig. 1 show the sum spectrum in the region of 2.223 MeV with the detectors in the indicated configuration, but with no shielding between them. A second measurement with 2.5 cm of Pb between the detectors reduced the area of the peak at 2.223 MeV by a factor of 16 and indicated that γ-ray scattering from one detector into the other was primarily responsible for the peak. If the peak were entirely due to such scattering, 3 cm of heavy metal (composition 90% W, 6% Ni, 4% Cu, $\rho = 16.7$ g/cm^2) would reduce it by a factor of 7 more than the Pb. The solid circles in Fig. 1 are the results of such a measurement and indicate that at least 98% of the events seen without the shield are due to γ-ray scattering from one detector into the other. From the data taken with the heavy-metal shield, the number of 2.223-MeV singles, the ^{60}Co coincidence efficiency, and the assumption of an isotropic angular distribution between the two photons, we derive an upper limit for the branching ratio for two-photon decay:

$$\sigma(2\gamma)/\sigma(\gamma) \leq 10^{-4}.$$

This ratio is a factor of 10 lower than the reported[1] branching ratio for unshielded detectors on opposite sides of the sample.

The significant difference between the present result and that reported in Ref. 1 can only be understood as due to a strongly asymmetric angular distribution for the two-photon process or to a misinterpretation by Dress *et al.*[1] of coincidence events observed in their geometry. In an attempt to differentiate between these alternatives, measurements were performed in the latter configuration, as indicated in Fig. 2. Spectra were obtained with and without 6-mm-thick Pb screens in an attempt to differentiate between two-photon-decay events and γ-ray scattering from one detector into the other. If the events observed at 2.223 MeV as shown in Fig. 2 were from two-photon decay, the branching ratio for this process would be $(0.6 \pm 0.14)\times 10^{-3}$ for the upper curve and $(0.3 \pm 0.2)\times 10^{-3}$ for the lower curve. However, the experimentally observed attenuation of coincidences by the Pb screens of a factor of 6 ± 4 is more consistent with γ-ray scattering from one detector into the other for which an attenuation factor of 5 is expected than with two-photon decay for which a factor of 3 is expected. Possible sources of γ-ray scattering from one detector into the other are (1) Doppler-shifted 0.511-MeV γ rays due to positron annihilation in flight,[3] (2) multiple Compton scattering, and (3) the summing in one detector of a positron-annihilation photon and a Compton-backscattered annihilation photon originating in the other detector. Calculations of these effects[4] indicate that the coincidences observed in the geometry of Fig. 2 and in the previous experiment[1] are mainly due to positron annihilation in flight. Those observed in the geometry of Fig. 1 without the heavy-metal shielding are similarly found to result from multiple Compton scattering and positron annihilation in flight.

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Note added.—Further measurements made in the configuration illustrated in Fig. 2 have provided an improved value of 4.8 ± 1.6 for the attenuation due to the Pb screens.

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Shell Structure of the ^{58}Ni Charge Density

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A very-high momentum-transfer ($q = 780$ MeV/c), elastic electron-scattering experiment on ^{58}Ni has been performed using the 600-MeV linac of Saclay. The charge density, extracted from (e,e) and muonic-x-ray data, exhibits considerably less structure than predicted by Hartree-Fock calculations.

Elastic electron scattering is the most powerful probe for the charge density $\rho(r)$ of the nuclear ground state, and recent experiments have yielded very detailed information on $\rho(r)$. The central question is then: What can one learn from these experiments about microscopic theories for the nuclear ground state?

The fluctuations in the density measured by these experiments[1-5] are very sensitive to the microscopic structure of the ground state. Qualitatively, the oscillations superimposed on the average density are understood. However, their amplitude seemed to be much smaller than predicted by shell-model calculations. This effect was assumed to provide information on the short-range nucleon-nucleon correlations[6-8] which lead to a general reduction in the amount of structure of $\rho(r)$.

But, for two reasons, the densities deduced from these experiments are not well suited for a conclusive comparison with theory. First, for nuclei with incompletely closed shells like calcium, the effects of short-range correlations cannot be isolated in the presence of 2p-2h (two-particle, two-hole) excitations.[9,10] Secondly, model densities prevent an unbiased investigation of the fine details of $\rho(r)$. One therefore has to use the much less model-dependent densities provided by recent analyses[11,12] of the same data. These new analyses of closed-shell nuclei show that, except for ^{48}Ca, the fluctuations of the densities determined by experiment are compatible with theory within experimental uncertainties. This is a consequence of the maximum momentum transfer