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Lifetime of the 0.119-Mev State of the N^{16} Nucleus*

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The mean life of the 0.119-Mev state of N^{16} has been measured and is found to be $7.83(1\pm0.04)\times10^{-6}$ second. This state was produced by means of the $N^{15}(d,p)N^{16}$ reaction with deuterons having a laboratory energy of 1.76 Mev. The experiment involved periodically directing the deuteron beam onto and then away from the target. The lifetime was determined by measuring the decay rate of the 0.119-Mev γ-ray activity during the periods when the beam was off the target.

INTRODUCTION

BOTH experimental and theoretical work have recently made significant contributions to an understanding of the nature of the four low-energy states of N^{16}. The experimental work has included studies[1,2] of the β decay of the ground state of N^{16} to various states of O^{16}, studies of the $N^{15}(d,p)N^{16}$ proton angular distributions in relation to stripping theory,[3,4] and studies of the γ decay of the N^{16} states following their production by means of the $N^{15}(d,p)N^{16}$ reaction.[5,6] Figure 1 shows some of the properties of the N^{16} states which have been inferred from these experiments.

The theoretical work of Elliott and Flowers[7] has helped to stimulate interest in such experiments, since it not only accounts for the existence of four such low-energy states for N^{16} but it predicts many of the properties that these states should have. Their work is based on an intermediate-coupling shell model in which the N^{16} states are found to arise from very nearly pure $p_{\frac{1}{2}}^{-1}s_{\frac{1}{2}}$ and $p_{\frac{1}{2}}^{-1}d_{\frac{5}{2}}$ configurations. The agreement between the theoretical work and the experimental findings is very encouraging.

That the 0.119-Mev state has a lifetime of the order of several microseconds was first noted by Wilkinson in a study of the delayed coincidences between γ transitions from the 0.392-Mev state to the 0.119-Mev state and from the 0.119-Mev state to the ground state.[5] Freeman and Hanna measured this lifetime more accurately by studies both of the delayed γ-γ coincidences and also of delayed coincidences between the protons which are emitted in the formation of the 0.392-Mev and 0.119-Mev states and the γ rays emitted by the 0.119-Mev state.[6] The result that they obtained is a mean life of $9.7(1\pm0.07)\times10^{-6}$ sec.

There are perhaps two reasons why a knowledge of this lifetime is interesting. The order of magnitude of the lifetime identifies the transition as a quadrupole transition, helping in the assignment of unique spins to the 0.119-Mev and 0.392-Mev states. In addition, an accurate determination of the lifetime provides one more point at which the validity of the theoretical calculations may be tested.

The present measurement of the lifetime of the 0.119-Mev state, using the $N^{15}(d,p)N^{16}$ reaction, differs from the previous measurements in that it employs a beam-interruption technique rather than a delayed coincidence method. The principle of the present technique can be simply stated in the following way: If the deuteron beam is turned off after it has fallen on the target for some time, the lifetime may be measured by observing the decay of the 0.119-Mev γ-activity of the target.

Since in the $N^{15}(d,p)N^{16}$ reaction the 0.119-Mev state is not only formed directly but is also produced by γ decay of the 0.392-Mev state, it is important that the lifetime of the 0.392-Mev state be short compared to that of the 0.119-Mev state. There is good reason to believe that this is the case since the γ transition between the 0.392-Mev and 0.119-Mev states is thought to be magnetic dipole. The single-particle estimate for the mean life of this transition, computed from the formula given by Blatt and Weisskopf[8] without statistical factors, is $(1.6)\times10^{-12}$ sec, and it may be seen from Wilkinson's survey of radiative transitions in light nuclei[9] that with few exceptions the measured mean

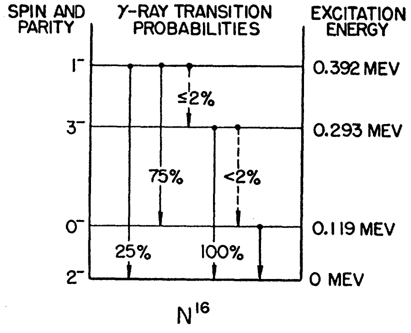

FIG. 1. Energy level diagram for the low-energy states of N^{16}.

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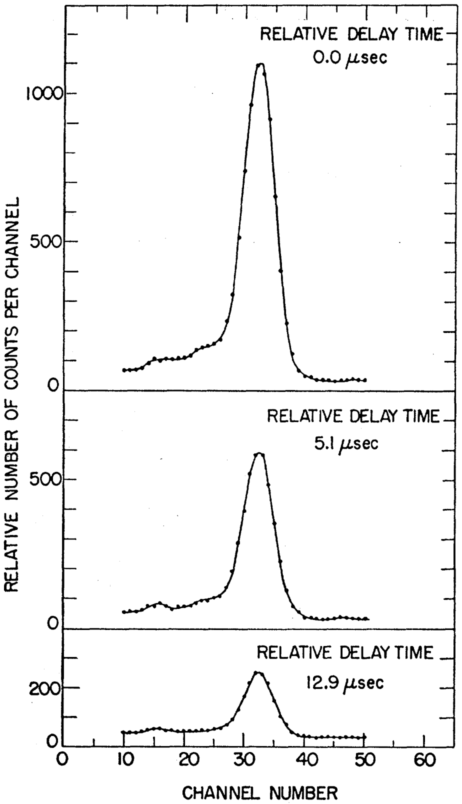

FIG. 2. Pulse-height spectra showing the 0.119-Mev γ-ray photopeak for three different delay times.

lives of known $M1$ transitions are less than a factor of 10^3 greater than their single-particle estimates.

EXPERIMENT

A beam of 1.76-Mev deuterons from the Kellog Laboratory 2-Mv Van de Graaff generator was passed between a pair of parallel electrostatic deflection plates roughly 5 cm long and 1 cm apart before being put through an electrostatic energy analyzer. The deflection plates were oriented at right angles to the analyzer plates so that they deflected the beam in a plane parallel to the analyzer plates. A voltage of about 1.8 kv was sufficient to deflect the beam onto a tantalum stop about 1.5 meters beyond the deflection plates, at the exit of the analyzer. When undeflected, the beam could pass on through a regulating and collimating slit system into a target chamber located about 1.2 meters beyond the tantalum stop.

The target containing N^{15} consisted of a nickel foil 2500 A thick onto which a layer of titanium of the same order of thickness had been evaporated. This layer of titanium was nitrided by heating it in an atmosphere of NH_3, of which the nitrogen had been enriched to 65% N^{15}. However, the layer also contained O^{16} as a contaminant and possibly more N^{14} than was introduced with the enriched NH^3.

The 0.119-Mev γ radiation was detected at a laboratory angle of 90° in a square prism of thallium-activated sodium iodide 1 in. by 1 in. by $\frac{3}{8}$ in. attached to a Dumont 6292 photomultiplier tube. The inner surfaces of the lead shielding which surrounded the scintillation crystal were lined with 0.010-inch tantalum sheet placed next to the lead and two layers of 0.018-in. tin sheet inside the tantalum. The lining served to degrade the energy of the fluorescent x-radiation from the lead and thus produce a cleaner γ-ray spectrum on the low-energy side of the 0.119-Mev photopeak. The pulses from the photomultiplier were sorted in a gated 100-channel pulse-height analyzer.

A periodically varying voltage whose waveform approximated a square wave was applied to the deflection plates. This signal allowed the beam to remain on the target for about 25 μsec and then deflected it away from the target for about the same length of time. When the beam was off, the 100-channel analyzer was turned on for an interval of about 8 microseconds. This interval began at a time which could be delayed roughly 1 to 16 microseconds relative to the time that the beam was turned off. A plot of the number of 0.119-Mev γ-ray counts recorded per run, suitably normalized, *versus* the delay time used in the run gave directly the decay curve of the radiation.

The length of a counting run was determined by the collection of a fixed amount of charge from the deuterons striking the target. However, this method of normalizing the number of counts per run was valid only if the shape of the beam current pulses remained constant from run to run. In order to allow for possible variations in this shape and permit more direct normalization of the data, a second counting system with a fixed delay was provided. This monitor system consisted of a 10-channel pulse-height analyzer which received pulses from the same photomultiplier as did the other analyzer and which also counted 0.119-Mev γ rays. This analyzer was turned on a fixed 2 μsec after the beam was deflected away from the target and remained on for about 16 μsec. In practice, the normalization of the number of counts per run for a given delay time by the number of counts recorded by the monitor did not seem to improve the consistency of the former numbers, and so for the later runs the monitor was not considered necessary.

The delay time intervals were measured by using an oscilloscope to compare the delay signals with the signal from a 4-megacycle crystal-calibrated frequency standard.

Examples of some of the best γ-ray pulse-height spectra obtained, showing the 0.119-Mev photopeak for three different delay times, are displayed in Fig. 2. The shoulder on the low-energy side of the photopeak, which decays with the photopeak, is presumably due to photoelectric events in the sodium iodide crystal in which the iodine K x-rays escape. For these particular spectra, the relative intensity of 0.119-Mev γ radiation was computed for each delay time by subtracting a background of 38 from the number of counts in each of channels 27 through 37 and summing the resulting numbers.

The relative intensity of 0.119-Mev radiation as a function of delay time is shown for a representative set of runs in Fig. 3 by means of open circles. The straight lines in this figure represent the mean life of $7.83(1\pm0.04)\times10^{-6}$ second which has been derived from several sets of runs.

The largest source of error in the analysis of this experiment seems to lie in the subtraction of the background from under the photopeak of the 0.119-Mev radiation. It is difficult to be certain of the shape of this background, and it is not impossible that this shape varies with delay time. The standard deviation of $\pm4\%$ assigned to the mean life is based on this background uncertainty together with some other smaller uncertainties.

Several different kinds of runs were made in a search for possible defects in the experimental technique. A target similar in construction to the N^{15} target but containing only natural nitrogen was substituted for the N^{15} target. However, no pulse-height peak or exceptional change in background appeared in the place of the 0.119-Mev radiation for any of the delay time-settings. The same was true when the beam was allowed to fall on a quartz beam stop, which greatly increased the radiation received by the counter during the time that the beam was on. Several sets of runs were made exposing the scintillation crystal to a constant intensity of 0.088-Mev γ rays as well as to the radiation from the N^{15} or the natural nitrogen target. This was done in order to verify directly that the counting efficiency did not change with delay time. The 0.088-Mev γ rays were obtained from a Cd^{109} source. The number of counts due to this source per unit time remained constant to an accuracy of about $\pm3\%$ over the range of delay times.

DISCUSSION OF RESULTS

It is interesting to compare the measured lifetime with the lifetime calculated by Elliott and Flowers for this transition.[7] They find that their intermediate-coupling shell model wave functions give a mean life of the order of 10^{-3} sec. They observe, however, that with the inclusion of collective effects, giving the nucleons involved in the transition an additional "effective" charge, they obtain a mean life of $3.8(1\pm0.4)\times10^{-6}$ sec, which they note is at least of the right order of magnitude to agree with experiment. The size of the effective charge that they choose is that which is necessary to account for the rate of the collectively-enhanced electric quadrupole transition between the 0.872-Mev and ground states of O^{17}.

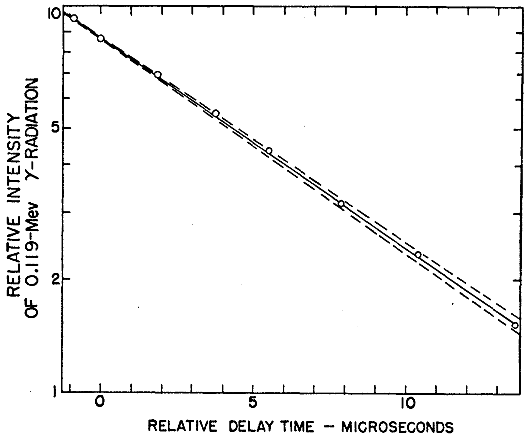

FIG. 3. Intensity of the 0.119-Mev γ radiation as a function of delay time. The open circles are experimental points. The straight lines represent a mean life of $7.83(1\pm0.04)\times10^{-6}$ sec.

The mean-life value measured here is not in very good agreement with the value $9.7(1\pm0.07)\times10^{-6}$ sec measured by Freeman and Hanna. A communication from Dr. Hanna concerning this discrepancy was helpful to the author in stimulating the use of the checks on the experiment which are described above, but the difference between the two results has not been resolved.

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