Gamma-ray widths in ^{15}N

R. Moreh,* W. C. Sellyey, and R. Vodhanel
Department of Physics, University of Illinois at Urbana-Champaign, Illinois 61801
(Received 21 August 1980)

The ground-state radiative widths of nine levels below 10.2 MeV in ^{15}N were measured using resonance fluorescence. The results are compared with various theoretical predictions and are found to best agree with very recent unpublished calculations in which the full $1\hbar\omega$ configurational basis is included in constructing the wave functions of the ^{15}N levels.

[NUCLEAR REACTIONS ^{15}N(γ,γ'), E=10.3, 11.4 MeV bremsstrahlung. Deduced E_x, Γ_0. Li^{15}NO$_3$ enriched target.]

I. INTRODUCTION

The ^{15}N nucleus has been studied extensively both theoretically and experimentally[1-11] as it neighbors the doubly magic ^{16}O nucleus. The ^{15}N ground state is usually regarded as a $p_{1/2}^{-1}$ proton hole state as evidenced experimentally by some pickup reactions.[1] The excited ^{15}N levels contain sizable 1p-2h components as found using the ^{14}N (d,p) reaction. One therefore expects ^{15}N to reveal not only a strong $M1$ strength via a $p_{1/2}^{-1} \to p_{3/2}^{-1}$ proton hole transition, but also a strong $E1$ strength by promoting p neutrons and protons to either $s_{1/2}$ or $d_{5/2}$ orbitals. The radiative widths of some of those levels may be studied using the resonance fluorescence method. This technique is selective as it photoexcites mainly levels with large Γ_0, large Γ_0/Γ, and $J^\pi = \frac{1}{2}^\mp, \frac{3}{2}^\mp$ (being related to the ^{15}N ground state, $J_0 = \frac{1}{2}^-$, by dipole absorption). Some particularly strong $E2$ excitations may also be observed.

Most of the earlier work[2-11] on ^{15}N concentrated on the study of level energies, spins, parities, and spectroscopic factors. All these quantities seem to have been successfully predicted by various theoretical calculations. However, the level widths which usually constitute the most sensitive test of any theoretical model have not yet been studied in great detail.

In the present work, the radiative widths of nine levels in ^{15}N below 10.2 MeV were determined using bremsstrahlung photons. The widths of five levels are reported for the first time. The results show very large deviations from the results of some earlier calculations[4] and a much better agreement with the most recent calculations by Millener.[12]

II. EXPERIMENTAL METHOD

Experimentally, the incident bremsstrahlung photons for the resonance fluorescence work were produced using 10.3 MeV and 11.4 MeV electron beams from the MUSL-2 accelerator of the University of Illinois having a 100% duty cycle. An electron current of ~15 μA and a gold radiator of 0.2 g/cm^2 thick were employed. The experimental system differed from that described in Ref. 13 only in the use of a 5 cm borated plastic shield (against fast neutrons) which surrounded the 50 cm^3 Ge(Li) detector. In addition, because of the

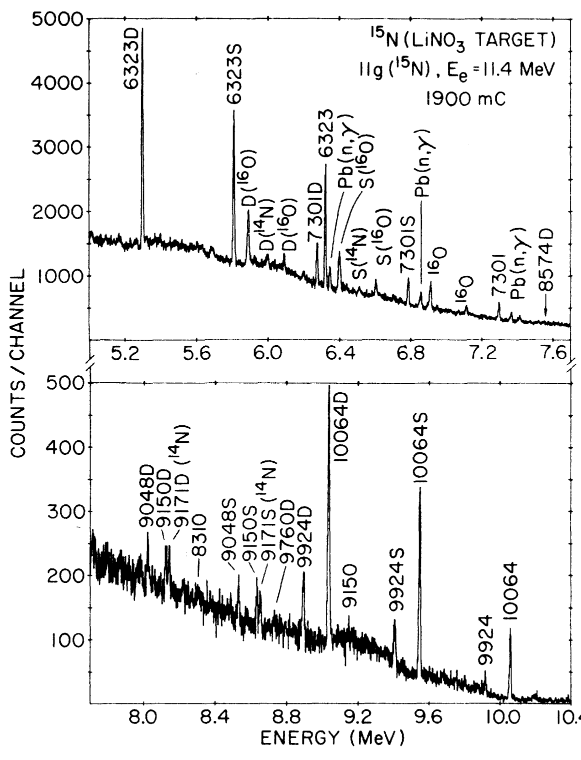

FIG. 1. Spectrum obtained using 11.4 MeV bremsstrahlung scattered from a ^{15}N target in the form of LiNO$_3$. Some lines due to ^{14}N(γ,γ) and ^{16}O(γ,γ) are also observed. A total charge of 1900 mC was deposited on the bremsstrahlung radiator, during a running time of ~40 h. S and D refer to single and double escape peaks, respectively.

smaller Z and mass of the target, a thinner hardener was used consisting of 2.0 cm lead and 2.5 cm Zn placed in front of the detector. The use of Zn instead of Cu as a hardener avoided the appearance of the strong "background" γ lines of the Cu (n,γ) reaction. The target consisted of a combination of two enriched $LiNO_3$ samples (99.3% ^{15}N and 42.7% ^{15}N) containing a total of 11.1 gm of ^{15}N which were placed inside a thin 10×10 cm^2 square-shaped styrofoam container. The scattered spectrum (Fig. 1) shows, apart from the elastically scattered γ lines of ^{15}N, other lines due to ^{16}O, ^{14}N, and background lines due to the $^{208}Pb(n,\gamma)$ reaction. The energies of the ^{15}N levels were determined (Table I) by using the ^{11}B and ^{24}Mg energies of Refs. 15 and 16 for calibration.

III. RESULTS AND DISCUSSION

The radiative widths of the ^{15}N levels were obtained from a knowledge of the product $N(E)\epsilon(E)$ of the incident photon flux and the detection efficiency[13] for levels in the range $E_\gamma = 4$–11 MeV. This was done using calibration lines in ^{11}B, ^{23}Na, ^{24}Mg, ^{31}P, and ^{208}Pb for which accurate widths were established by self-absorption measurements. In deducing Γ_0 and Γ of the ^{15}N levels (Table I), it was necessary to take the spins and branching ratios Γ_0/Γ from the literature.[1] The present value for the $\frac{3}{2}^-$, 6.323 MeV level is in excellent agreement with previous results obtained using the (e,e') reaction[6] and the (γ,γ') reaction with n-capture γ rays.[8] The same is true of the 9.760 MeV level.[9] However, a relatively large deviation occurs for the $\frac{3}{2}^+$, 7.301 MeV level.[7] Furthermore, the $\frac{1}{2}^+$, 8.31 MeV and the $\frac{3}{2}^+$, 8.57 MeV levels were very weakly excited and hence only a rough determination of their width could be made. The $\frac{1}{2}^+$, 5.299 MeV level was not observed in the present measurement because its width ($\Gamma_0 = 0.026$ eV) is below the sensitivity of the present measurement. The $\frac{5}{2}^+$, 5.270 MeV level is also known to have a very small width ($\Gamma_0 = 2.5\times10^{-4}$ eV). Nevertheless, it was observed as it was fed via secondary transitions from higher levels.

A. The $M1$ and $E2$ transitions

Theoretically, the properties of the $A = 15$ levels were studied by several investigators.[2-5] The most detailed calculations were carried out by Lie and Engeland[4] who considered levels with excitations below 12 MeV. In this calculation, a weak coupling model was used. The positive parity eigenstates were taken to be admixtures of 1p-2h and 3p-4h configurations, where the particles are assumed to occupy the $(2s,1d)$ orbitals and the holes occupy the p orbital. The negative parity eigenstates were taken to be admixtures of 0p-1h, 2p-

TABLE I. Measured widths and excitation energies in ^{15}N. The values of J^π and Γ_0/Γ were taken from Refs. 1 and 17.

Ex (keV)	J^π	Present Γ_0 (eV)	Γ_0/Γ [a] (%)	Others Γ_0 (eV)	Theory Γ_0 [e] (eV)	Γ_0 [f] (eV)	Γ_0 [g] (eV)
6323±1	$\frac{3}{2}^-$	3.12±0.18	100	3.2 ±0.3 [b]	2.8		
7301±1	$\frac{3}{2}^+$	1.08±0.08	99.3±0.7	2.4 ±0.9 [c]	0.2	1.1	1.02
8310±4	$\frac{1}{2}^+$	0.3 ±0.2	79 ±2		0.005	0.006	0.26
8575±4	$\frac{3}{2}^+$	0.3 ±0.3	33 ±2		0.32	0.07	0.41
9048±1	$\frac{1}{2}^+$	1.2 ±0.2	92 ±2		2.6		0.78
9150±1	$\frac{3}{2}^-$	0.47±0.12	100	0.3 ±0.8			
9760±1	$\frac{5}{2}^-$	0.21±0.07	81.5±3	0.20±0.5 [d]	0.004		
9924±1	$\frac{3}{2}^-$	1.6±0.2 [h]	77.6±2		1.12		
10064±1	$\frac{3}{2}^+$	6.3 ±0.4	96.0±0.7		0.11	2.6	5.5

[a] Reference 1.
[b] References 6 and 8.
[c] Reference 7.
[d] Reference 9.
[e] Reference 4.
[f] Reference 14.
[g] Reference 12.
[h] The measured width was obtained by assuming that $J = \frac{3}{2}$ and identification with the theoretical $(\frac{3}{2}^-)_2$ model state.

3h, and 4p-5h configurations. The calculated widths are given in Table I, which reveals very large deviations from experiment for most levels. The measured $M1$ transition width of the 6.323 MeV level is in relatively good agreement with the predicted value (Table I). This level is identified with the $(\frac{3}{2}^-)_1$ model level of Ref. 4, which according to this notation is the first excited state with $J^\pi=\frac{3}{2}^-$. There is some ambiguity concerning the identification of the $(\frac{3}{2}^-)_2$ model state of Lie and Engeland. Most of the earlier data[1] list the 9.15 MeV level as the only $\frac{3}{2}^-$ level below 10.1 MeV. However, recent data[17] seems to establish a $J^\pi=\frac{3}{2}^-$ assignment to the 9.92 MeV level. It also appears that this level is more likely to be identifiable with the $(\frac{3}{2}^-)_2$ model state and not with the $(\frac{3}{2}^-)_3$ state because it is the lowest 2p-3h, $\frac{3}{2}^-$ state which contains some single hole component. Table I shows a good agreement between the widths of the calculated and measured values for the 9.92 MeV level assuming that the suggested identification is correct. Further, the 9.15 MeV level seems to contain an appreciable 4p-5h component as it was very strongly populated via the $^{11}B(^7Li, t)$ reaction.[18] However, the energy of the lowest model level[4] containing a large 4p-5h component is at 12.1 MeV for which no width was calculated. This means that a large discrepancy between theory and experiment occurs for the excitation energy of this level.

It is also of interest to note that the predicted $E2$ width of the 9.76 MeV level is smaller by a factor of ≥ 50 than the measured width. This comparison of $M1$ and $E2$ widths with calculations (Table I) should be treated with some reserve. This is because Ref. 4 refers to the model levels of the mirror ^{15}O nucleus which for $M1$ and $E2$ widths may differ from the ^{15}N levels because the isovector contributions of the two mirror nuclei differ in sign leading in some cases to strong cancellation effects. The predicted $E1$ widths however, should be the same for both ^{15}N and ^{15}O.

B. The $E1$ transitions

Of special interest among all levels is the 10.06 MeV ($J^\pi=\frac{3}{2}^+$), found to have $\Gamma_0=6.3$ eV. This level has a large 1p-2h component of $^{14}N(1^+, T=0) \times d_{5/2}$ configuration as evidenced by the $l=2$ angular distribution in the $^{14}N(d,p)$ reaction[1]; it is predicted by Lie and Engeland[4] to have Γ_0 smaller by a factor of ~60 than the measured value. It should be remarked that the large deviations between the predicted values of Ref. 4 and the present data are not due to errors in the identification of the model levels with experimental levels. In fact, the calculated total $B(E1)$ strength to the ground state of all six model levels of Ref. 4 (three with $J^\pi=\frac{3}{2}^+$ and three with $J^\pi=\frac{1}{2}^+$ and $T=\frac{1}{2}$ can be seen to be a factor of ~4 smaller than the measured value.

It may be noted that a different calculation by Kurath[14] (Table I) which was restricted to $1\hbar\omega$ excitations, namely, to $(1s)^4(1p)^{10}(2s1d)^1$ plus $(1s)^3(1p)^{12}$ configurations, yielded a much better agreement with the experimental widths of the 7.301 and 10.06 MeV levels. However, the smaller number of degrees of freedom caused by limiting the configuration space yielded a smaller number of levels with $J^\pi=\frac{1}{2}^+, \frac{3}{2}^+$ than observed experimentally. Hence, no detailed comparison with the present data is possible. Nevertheless, the calculated total $B(E1)$ strength of the above six levels with $T=\frac{1}{2}$ to the ground state is a factor of ~2 lower than the measured value, which is in better accord with the data than the results of Ref. 4.

The best overall agreement with the present data was obtained by Millener,[12] in another calculation, using the SU(3) basis for obtaining the ^{15}N wave functions. In this calculation the full $1\hbar\omega$ basis and some of the important $3\hbar\omega$ configurations were included. The truncation of the $3\hbar\omega$ basis was described in Ref. 11. Table I shows that apart from some $M1$ levels, a good agreement exists between the predicted and measured values. In addition, the total calculated $B(E1)$ strength for the six model levels is almost identical to the measured value.

It should be noted that the essential difference between the calculations of Millener[12] and those of Lie and Engeland comes from the use of the full $1\hbar\omega$ basis in the calculation of the positive parity states. The present results can therefore be viewed as illustrating the importance of including the full $1\hbar\omega$ basis in such calculations.

ACKNOWLEDGMENTS

One of us (R.M.) would like to thank Dr. P. J. Ellis and Dr. B. H. Wildenthal for some useful remarks, and Dr. D. Kurath and Dr. D. J. Millener for illuminating discussions and for sending us their results before publication. This research, including the development and operation of MUSL-2 and its experimental areas, was supported by the National Science Foundation.

*Present address: Physics Department, Ben-Gurion University of the Negev, Beer-Sheva, Israel.

[1]F. Ajzenberg-Selove, Nucl. Phys. A268, 1 (1976).
[2]A. R. Poletti, E. K. Warburton, and D. Kurath, Phys. Rev. 155, 1096 (1967).
[3]A. P. Shukla and G. E. Brown, Nucl. Phys. A112, 29 (1968).
[4]S. Lie and T. Engeland, Nucl. Phys. A169, 617 (1971); A267, 123 (1976); S. Lie, T. Engeland, and G. Dahl, *ibid.* A156, 449 (1970).
[5]B. S. Reehal and B. H. Wildenthal, Part. Nucl. 6, 137 (1973).
[6]G. A. Beer, P. Brix, H. G. Clerc, and B. Laube, Phys. Lett. 26B, 506 (1968).
[7]J. C. Kim, H. S. Caplan, and I. P. Auer, Phys. Lett. 56B, 442 (1975); J. C. Kim, H. S. Caplan, and J. C. Bergstrom, Nucl. Phys. A246, 282 (1975).
[8]R. Moreh and O. Shahal, Nucl. Phys. A252, 429 (1975).
[9]E. J. Ansaldo *et al.* , Can. J. Phys. 55, 2129 (1977).
[10]R. P. Beukens, Ph.D. thesis, University of Toronto, 1976.
[11]D. E. Alburger and D. J. Millener, Phys. Rev. C 20, 1891 (1979).
[12]D. J. Millener (private communication).
[13]D. F. Coope, L. E. Cannell, and M. K. Brussel, Phys. Rev. C 15, 1977 (1977).
[14]D. Kurath (private communication).
[15]F. Ajzenberg-Selove, Nucl. Phys. A248, 1 (1975).
[16]P. M. Endt and C. Van der Leun, Nucl. Phys. A310, 1 (1978).
[17]V. Bechtold *et al.*, Phys. Lett. 72B, 169 (1977).
[18]W. Kohler, H. Schmidt-Boching, and K. Bethge, Nucl. Phys. A262, 113 (1976).