Shell-model study of the giant dipole states in ^{15}N

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We have calculated the photoabsorption cross sections due to electric dipole transitions from the ground state of ^{15}N to excited states in the giant-resonance region using a two-hole, one-particle shell model with zero-range Soper and with separable Tabakin residual interactions. The calculated results are compared with available experimental data and the need for further experimental work is suggested.

[PHOTONUCLEAR REACTIONS Calculated total cross sections for ^{15}N (γ, p) + (γ, n) + (γ, d).]

We have calculated the photoabsorption cross sections due to $E1$ transitions from the ground state of ^{15}N to excited states in the giant resonance region using a two-hole, one-particle (2h-1p) shell model with zero-range Soper and separable Tabakin residual forces. The present model is analogous to the 1h-2p model employed in a recent calculation[1] of the photoabsorption cross sections in ^{13}C and ^{17}O. The calculated results are compared with the available experimental cross sections and the need for further experimental work is suggested.

Electric and magnetic transitions to the giant-resonance states of ^{15}N have been studied both experimentally and theoretically by several authors.[2-7] The theoretical calculations by Fraser, Garnsworthy, and Spicer[6] and by Hsieh[7] employed 2h-1p shell-model configurations with various residual forces and the results were compared with experimental $^{15}N(\gamma, p_0)^{14}C$ cross sections of Rhodes and Stephens.[2] In a subsequent paper Harakeh *et al.*[5] compared predictions of a 2h-1p shell model with measured differential cross sections taken at 90°. Since total (γ, p) cross sections were unavailable at the time, the theoretical predictions mentioned above had only been compared with the (γ, p_0) cross sections. Therefore, the more recent experimental measurements of total (γ, p) cross sections by Denisov, Kulchitskii, and Chubukov[3] merit attention, especially since these authors report that transitions to the two excited states of ^{14}C at $E_x = 7.0$ and 10.7 MeV account for an integrated photoabsorption cross section $\sigma_{int} = 52$ MeV mb, while transitions to the ground state of ^{14}C account for only $\sigma_{int} = 21$ MeV mb. From their measurements Denisov and Chubukov[4] have shown that the integrated cross section for the reaction $^{15}N(\gamma, d)^{13}C$ is only about 1.0 MeV mb. The only important missing piece of information seems to be the measured $^{15}N(\gamma, n)^{14}N$ cross sections. In the absence of these, we compare our theoretical predictions with both the measured (γ, p_0) and (γ, p) cross sections and, using reasonable estimates for the total cross section just for normalization purposes, we verify that the isospin components of the calculated cross section satisfy the isospin sum rule.

The method of calculation of nuclear levels and wave functions in the framework of the particle-hole shell model is standard[8] and need not be discussed here. We have assumed a closed core of ^{16}O which is filled up to the $1p_{1/2}$ harmonic oscillator state. The oscillator parameter was chosen to be $m\omega/\hbar = 0.36$ fm^{-2}. Since we consider only transitions caused by the $E1$ and $M2$ operators, only non-normal parity basis states are formed (of positive parity, since the ground state of ^{15}N has $J^\pi = \frac{1}{2}^-$). These are constructed by considering up to a maximum of two holes in the single-particle states $1s_{1/2}$, $1p_{3/2}$, and $1p_{1/2}$ and up to a maximum of one particle in $1d_{5/2}$, $2s_{1/2}$, and $1d_{3/2}$ states. The single-particle energies for these states were taken to be the same as those of Fraser, Garnsworthy, and Spicer.[6] The $1s_{1/2}$ particle energy, which is uncertain by several MeV, was taken to be -45 MeV instead of -47.7 MeV. The residual interactions used were the same as those in our previous calculation[1] of photoabsorption cross sections in ^{13}C and ^{17}O and consisted of a zero-range Soper interaction[9] and a separable Tabakin interaction.[10]

The calculated integrated cross sections are presented in Fig. 1(a) and (b) in absolute units as a histogram with an arbitrary 2-MeV width for each level. Shown in Fig. 1(c) are measured cross sections for the reaction $^{15}N(\gamma, p_0)^{14}C$ from Rhodes and Stephens,[2] and for the reaction $^{15}N(\gamma, p)^{14}C$ from Denisov, Kulchitskii, and Chubukov.[3] Since measured cross sections[4] for the reaction

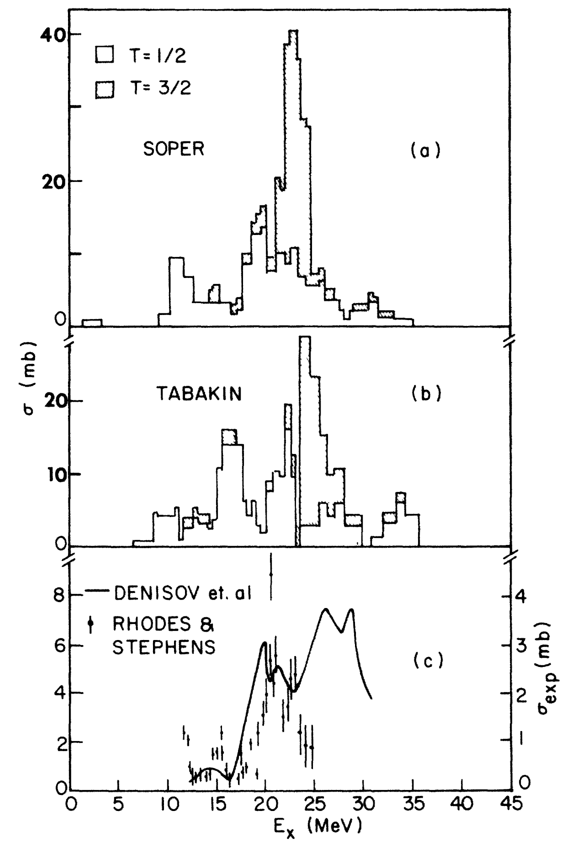

FIG. 1. Total photoabsorption cross sections in ^{15}N calculated using a shell model with (a) the Soper and (b) the Tabakin residual interactions. Shown in (c) are experimental $^{15}N(\gamma, p_0)\,^{14}C$ cross sections from Rhodes and Stephens (Ref. 2) (scale on the right) and $^{15}N(\gamma,p)$-^{14}C cross sections from Denisov, Kulchitskii, and Chubukov (Ref. 3) (scale on the left).

$^{15}N(\gamma, d)^{13}C$ are relatively very small, these are not shown. The only remaining mode of disintegration of ^{15}N expected to have significant cross sections is the reaction $^{15}N(\gamma, n)^{14}N$. Since measured values for this reaction have not been reported, a full comparison between theory and experiment is not possible. However, considering the similarity of (γ, p) and (γ, n) cross sections in the case of neighboring nuclei such as ^{13}C and ^{11}B, it is not unreasonable to think that the two broad peaks (each split into two smaller peaks) in the measured total (γ, p) cross section in ^{15}N may fall at the same energies as the corresponding peaks in the (γ, n) cross sections. With this assumption, we may tentatively identify the broad peak at $E \simeq 19$ MeV in (a) and the one at $E \simeq 16$ MeV in (b) with the experimental peak at $E \simeq 20$ MeV in (c). Similarly, the broad peak at $E \simeq 23$ MeV in (a) and the one at $E \simeq 25$ MeV in (b) may be tentatively identified with the experimental peak at $E \simeq 27$ MeV in (c). The two theoretical peaks at $E \simeq 23$ MeV in (a) and at $E \simeq 25$ MeV in (b) contain mostly $T = \frac{3}{2}$ states, while those at $E \simeq 19$ MeV in (a) and at $E \simeq 16$ MeV in (b) contain mostly $T = \frac{1}{2}$ states.

Like the observed photoabsorption cross sections[1] of ^{13}C, those of ^{15}N also exhibit a splitting of the giant-resonance peak into two smaller peaks. Our calculation shows that this splitting corresponds to an isospin splitting, in which the upper, predominantly $T = \frac{3}{2}$, peak is clearly separated from a lower, predominantly $T = \frac{1}{2}$, peak, with another (also $T = \frac{1}{2}$) "pygmy" resonance located at still lower energies.

The sum rule given by O'Connell[11] for the bremsstrahlung-weighted cross section may be written for the case of ^{15}N as

$$\int_0^\infty \frac{\sigma(\frac{1}{2})dE}{E} - \frac{1}{2}\int_0^\infty \frac{\sigma(\frac{3}{2})dE}{E} = \frac{\pi^2 e^2}{3\hbar c}\,[N\langle R_n^2\rangle - Z\langle R_p^2\rangle]\,, \qquad (1)$$

where $\langle R_{n,p}^2\rangle$ are the mean-square neutron and proton radii. Adopting a value[12] of $\langle R_p^2\rangle^{1/2} \simeq \langle R_n^2\rangle^{1/2} = 2.68$ fm, the right-hand side of Eq. (1) becomes 1.72 mb. The values for the left-hand side of Eq. (1) predicted by our model are 1.87 mb with the Tabakin interaction and 1.53 mb with the Soper interaction, where we have normalized our total integrated cross section to an estimated experimental value of 124 MeV mb. This value was obtained as a contribution of 74 MeV mb measured for the (γ, p) plus (γ, d) reactions (see above), and of 50 MeV mb which was estimated for the not-yet-measured (γ, n) cross section by assuming the $(\gamma, n)/(\gamma, p)$ ratio measured for ^{11}B (a one-hole nucleus) to hold approximately for the present case also.

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