Single-neutron excitations in ^{18}N

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States in ^{18}N have been populated in the neutron-adding (d,p) reaction on the short-lived ^{17}N beam. Previously observed levels, found in this work at excitation energies of 0.12(1) MeV and 0.74(1) MeV, have been identified as those expected from a proton $0p_{1/2}$ hole coupled to the ^{19}O $5/2^+$ ground state. A new state at 1.17(2) MeV is consistent with the coupling of the $1/2^-$ proton-hole state to the excited $1/2^+$ state in ^{19}O. Orbital angular momentum assignments and spectroscopic factors were determined from the measured angular distributions through a distorted wave Born approximation analysis. Systematics for the $(0d_{5/2}1s_{1/2})^3$ neutron configurations in the $N=11$ isotones, ^{17}C, ^{18}N, and ^{19}O are discussed and comparisons to p-sd shell-model calculations are made.

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I. INTRODUCTION

The nucleus ^{18}N ($Z=7$, $N=11$) lies between ^{19}O, which has a ground-state neutron configuration $(0d_{5/2})^3_{J=5/2}$ [1], and ^{17}C, where the $3/2^+$ ground state with a $(0d_{5/2})^3_{J=3/2}$ neutron configuration resides 0.33 MeV below the $5/2^+$ state [2–20]. The location of the $1/2^+$ state, having a dominant $(0d_{5/2})^2(1s_{1/2})^1$ neutron configuration, is known to change dramatically with isospin from an excitation energy (E^*) of 0.22 MeV in ^{17}C [2–20] to $E^*=1.47$ MeV in ^{19}O [1], similar to the situation in the $N=9$ isotones [2,21–24]. We have attempted to identify the neutron configurations of low-lying states in the intermediate nucleus ^{18}N using the (d,p) reaction.

Previous measurements on ^{18}N have reported eight levels below the neutron separation energy ($S_n=2.828(24)$ MeV [25]) at $E^*=0.0, 0.115, 0.587, 0.742, 1.735, 2.21(2), 2.42(2)$, and 2.614 MeV (energy uncertainties are $\leqslant 1$ keV if not explicitly given) with only the ground-state spin assigned as $J^\pi=1^-_1$ [1,26–35]. Tentative assignments of $J^\pi=(2^-_1), (2^-_2)$, and (3^-_1) were made in Ref. [28] to the first three excited states and have remained consistent with the recent experimental data [29–31,33–35]. A summary and a graphical representation of these earlier works is given in Fig. 1 of Ref. [34].

The ^{17}N ground state has $J^\pi=1/2^-$ and is likely dominated by the $(\pi 0p_{1/2})^{-1}(\nu 0d_{5/2})^2$ configuration. Predominant states in ^{18}N to be populated in the ^{17}N(d,p) reaction will therefore have a proton hole $(0p_{1/2})^{-1}$ coupled to the $(0d_{5/2})^3$, $(0d_{5/2})^2(1s_{1/2})^1$, and $(0d_{5/2})^2(0d_{3/2})^1$ sd neutron configurations. The first of these neutron configurations gives rise to $J=5/2$, 3/2, and 9/2 states, with only the 5/2 and 3/2 expected at low excitation energy. The $J=5/2$ and 3/2 neutron spins and the 1/2 proton hole produces two sets of levels with $J^\pi=2^-, 3^-$ and $1^-, 2^-$, respectively, in ^{18}N. The latter doublet, based on its seniority $\nu=3$ neutron configuration, should not be populated appreciably in single-neutron adding. The 1/2 proton hole coupled to the $(0d_{5/2})^2(1s_{1/2})^1$, $J=1/2$ neutron configuration results in $J^\pi=1^-, 0^-$ states with $\ell=0$ angular distributions. All states involving considerable $0d_{3/2}$ neutron occupation will lie above the neutron separation energy. To a first approximation six low-lying levels are expected in ^{18}N, one with $J^\pi=3^-$, two with 2^-, two with 1^-, and one with 0^-. We expect appreciable overlap with four of these (one of each spin) in the neutron-adding (d,p) reaction.

II. EXPERIMENT

The Argonne National Laboratory ATLAS In-Flight Facility [36] was used to produce a radioactive ^{17}N ($T_{1/2}=4.17$ s) beam via proton removal from an ^{18}O^{8+} primary beam at 14.7 MeV/u on a 15 mg/cm^2 Be target. The secondary beam had an energy of 13.6 MeV/u, a typical rate of $\sim 2\times 10^4$ particles per second on target, and a purity ranging between $\sim$25–75%. The main contaminants in the secondary beam were ^{18}O^{7+} at 12.2 MeV/u and ^{14}C^{5+} at 14.4 MeV/u as determined by a Si detector telescope at zero degrees. The various reaction channels appearing due to multiple beam species were distinguished by requiring a coincidence with a

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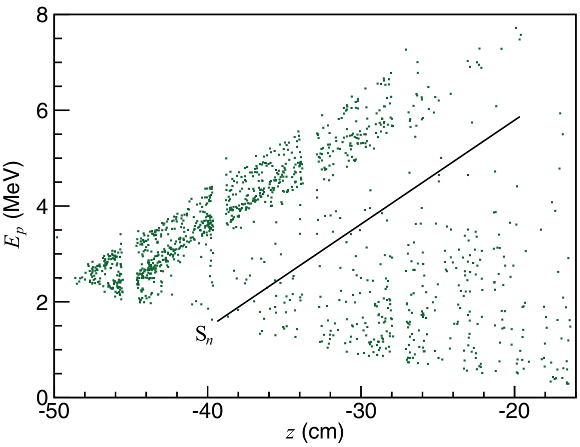

FIG. 1. (Color online) Proton energies (E_p) as a function of the longitudinal distance from the target (z) for the $^{17}N(d,p)^{18}N$ reaction in inverse kinematics. The events shown required a coincidence in the recoil detector telescope with either ^{18}N ions for bound states, or ^{17}N for unbound ones.

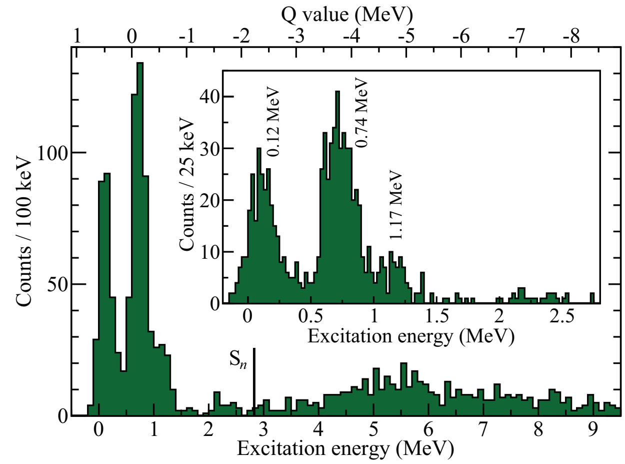

FIG. 2. (Color online) The measured excitation-energy (Q-value) spectrum for the $^{17}N(d,p)$ reaction with the same data set as is in Fig. 1. An expanded region of the excitation energy below the neutron separation energy (S_n) is shown in the inset.

heavy-ion recoil, identified in the Si recoil detector telescope, which covered $\theta_{lab} \sim 0.4$–2.2°. Data were collected for the $^{18}O(d,p)^{19}O$ reaction at two beam energies. The first was taken before the radioactive beam measurement at 14.7 MeV/u, utilizing the primary ^{18}O beam. The second was taken at 12.2 MeV/u in parallel with the $^{17}N(d,p)$ measurement making use of the secondary beam contamination. The higher energy ^{18}O beam data were used for the initial experimental setup and for energy calibrations, and the combination of the two data sets provided consistency checks of the analysis.

The experimental setup and analysis procedures are analogous to those described in Ref. [37] and only details specific to this measurement are given here. The measurement was made using HELIOS [38,39] with its maximum magnetic field strength of 2.85 T. The HELIOS position-sensitive Si detector (PSD) array detected the outgoing protons covering a longitudinal distance of $-50.8 < z < -16.3$ cm (upstream) from the target and it was positioned within the uniform magnetic field region. Deuterated polyethylene (CD_2) targets of nominal thickness 140 and 220 μg/cm^2 were used. Downstream of the target a monitor detector for scattered deuterons was fixed at $z = 12.0$ cm, a recoil detector telescope was located at 132.6 cm, and a zero degree Si detector telescope was placed at 139.2 cm behind a Ta mesh that reduced the effective beam intensity by a factor of $\sim$100. The energy response of the PSDs was calibrated using the 14.7 MeV/u ^{18}O beam and known Q values from the $^{18}O(d,p)^{19}O$ reaction. Protons were identified by their times-of-flight, measured with respect to the accelerator radio frequency. To distinguish protons originating from the reactions on different secondary beam components, a coincidence requirement was enforced between protons and a heavy-ion recoil. Protons identified in this manner, having either a ^{18}N or ^{17}N recoil coincidence, are shown in Fig. 1.

Mass values from Ref. [25] were used to determine the Q-value and excitation-energy spectra in Fig. 2, where three prominent peaks are visible. The measured Q value for the lowest lying state in ^{18}N was 0.48(4) MeV, ~ 0.12 MeV below the known ground-state value of 0.604(24) MeV [25]. Using an identical set of proton energy and position calibrations, the $^{18}O(d,p)$ reaction Q value to the ^{19}O ground state was found to be 1.74(4) MeV from the 12.2 MeV/u data, in agreement with the known value of 1.731(3) MeV [25]. The dominant uncertainty in the Q values from the present work is the secondary beam energy, with small contributions from the proton energy and position calibrations. The resolution in the ^{18}N spectrum was $\sim$275 keV FWHM, largely due to the properties associated with the radioactive beam, and it represents data from both targets. Relative differential cross sections to states in ^{18}N are accurate to within a few percent. Relative cross sections between excitations in ^{19}O (from the 12.2 MeV/u data) and ^{18}N were measured to $\sim$8% largely due to uncertainty in the beam composition. Absolute cross sections were not obtained for the radioactive beam measurement due to noise in the monitor detector. This had no impact on the discussions presented below. Center-of-mass angles were calculated from known quantities (Eq. (3) of Ref. [37]) and a single ring of four PSDs, which covered $\Delta z = 5$ cm in longitudinal distance, was separated into two angular bins when statistics allowed. Angular distributions are shown in Figs. 3(a) and 3(b) for the excitations in ^{18}N at 0.12(1), 0.74(1), and 1.17(2) MeV.

A distorted wave Born approximation (DWBA) analysis was used to extract relative spectroscopic factors (S) (the isospin factor $C^2 = 1$ in this reaction) and spectroscopic strengths

$$GS = \frac{2J_f + 1}{2J_i + 1} S \propto \frac{\sigma_{\rm Exp}}{\sigma_{DWBA}}, \tag{1}$$

from the measured cross sections, where $J_i = 1/2$ (^{17}N ground state) and J_f is the spin of the state in ^{18}N. Optical model parameter sets $D1$ and $P1$ from Table I of Ref. [40] best described the angular distributions of the $^{18}O(d,p)^{19}O$ data and so they were used as the distorting potentials for the

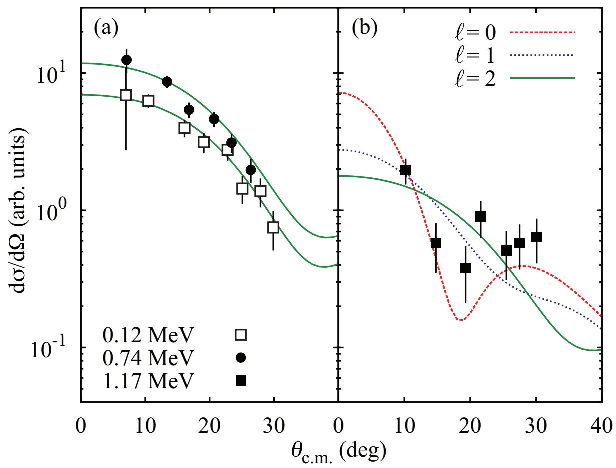

FIG. 3. (Color online) Measured angular distributions (data points) with the center-of-mass ($\theta_{\mathrm{c.m.}}$) angles representing the centers of the angle bins. Statistical uncertainties are given by vertical error bars. DWBA angular distributions are shown by the various lines (see text for details).

^{17}N(d,p) analysis. The bound-state potential depth was varied to reproduce the binding energies of the final states and a bound-state radius parameter $r_0 = 1.25$ fm and diffuseness $a = 0.65$ fm were used. The DWBA angular distributions were calculated using PTOLEMY [41] and the distributions are shown normalized to the data in Fig. 3. The extracted spectroscopic factors and strengths are given in Table I. Variations due to the bound-state parameters and the different optical-model parameters resulted in relative uncertainties in S (GS) of $\sim$20% for $\ell = 0$ states and $\sim$5% for $\ell = 2$ states in ^{18}N. The absolute normalization scale (N) on to the spectroscopic factors is described in detail at the end of Sec. III following the discussion on ℓ and J^π assignments to the observed peaks in Fig. 2.

TABLE I. Spectroscopic factors (S) and spectroscopic strengths (GS) for the ^{17}N$(d,p)^{18}$N reaction. Relative uncertainties are quoted explicitly. Absolute uncertainties in the normalized GS and S are estimated at $\pm$30%.

E^*(MeV)	$\ell(\hbar)$	J^π	GS [This work]	S [This work]
0.00[a]	2	1_1^-[a]	$\leqslant$0.10	$\leqslant$0.07
0.12(1)[b]	2	2_1^-[b]	1.68(8)	0.67(3)
0.587[a]	2	(2_2^-)[a]	$\leqslant$0.13	$\leqslant$0.05
0.74(1)[b]	2	3_1^-[b]	2.42(12)	0.69(3)
1.17(2)[b]	0	(1_2^-)[b,c]	1.44(29)[d,e]	0.96(19)
		$(0_1^- \& 1_2^-)$[b,f]	1.44(29)[g]	0.72(14)[h]

[a]Taken from previous works [1].
[b]Present work.
[c]Considering a single state at 1.17 MeV.
[d]$GS = 0.30(2)$ for $\ell = 2$, 0.52(3) for $\ell = 1$.
[e]$GS = 1.02$ and 0.13 for the $\ell = 0$ and 2 components of the composite distribution fit.
[f]Considering the 1.17-MeV state to be an $\ell = 0$ doublet.
[g]Summed GS for the 0_1^- and 1_2^- states.
[h]Assumed equivalent values of S for the 0_1^- and 1_2^- states.

The procedure for the extraction of the spectroscopic factors was checked using both sets of ^{18}O(d,p) data (beam energies of 14.7 MeV/u and 12.2 MeV/u). Using the same optical-model parameters as stated above, spectroscopic factors were extracted for the ground ($\ell = 2$, $J^\pi = 5/2^+$) and 1.47 MeV ($\ell = 0$, $J^\pi = 1/2^+$) states in ^{19}O. The ratios of $\ell = 2$ to $\ell = 0$ for these two states are 0.68(17) and 0.41(10), for the 12.2 MeV/u and 14.7 MeV/u ^{18}O beams, respectively, which are consistent with the 0.57(9) value of Ref. [42].

III. RESULTS

These data show firm evidence for the observation of excitations in ^{18}N at $E^* = 0.12(1)$, 0.74(1), and 1.17(2) MeV and an additional tentative state at $E^* \sim 2.2$ MeV, all below the neutron separation energy [$S_n = 2.828(24)$ MeV]. As distinct levels, these three energies account for three of the four states expected in the (d,p) reaction. Some single-particle strength was also found between the one- and two-neutron separation energies, $2.83 < E^* < 8.71$ MeV, however, no energy centroids were extracted and the data span too small of a region in angle for meaningful angular distributions to be constructed. The measured states at 0.12 MeV and 0.74 MeV correspond to those previously observed at 0.115 MeV and 0.742 MeV [1] and which were given tentative spin-parity assignments of $J^\pi = (2_1^-)$ and (3_1^-), respectively [28]. A level at 1.17(2) MeV had not been previously identified. An estimated upper limit on the population of the ground state is $\leqslant$6% of the summed cross section of the 0.12-MeV level, and the population of the known 0.587-MeV state is $\leqslant$5% of the summed cross section for the 0.74-MeV level.

Data for the two peaks at 0.12 MeV and 0.74 MeV have distinct $\ell = 2$ angular distributions [solid-green lines in Fig. 3(a)] and they make up the expected $J^\pi = 2^-, 3^-$ doublet belonging to the $(\pi 0p_{1/2})^{-1}(\nu 0d_{5/2})^3_{J=5/2}$ single-particle configuration. It is expected that their relative spectroscopic factors will be nearly equal, mirroring the corresponding $(\pi 0p_{1/2})^{-1}(\nu 0d_{5/2})^1$ states in ^{16}N at 0.00 and 0.298 MeV [43,44]. The ratio of the spectroscopic strengths for these two states is 1.5(1), which is consistent with the expected value of 7/5 if the assignments are indeed $J^\pi = 3^-$ and 2^-. This is clear evidence in favor of the previously suggested spin parities [28,33,45] and as such we no longer list these as tentative (Table I).

The limited population of the ground state and the 0.587-MeV state indicates they are likely based on the proton $0p_{1/2}$ hole coupled to the $\nu = 3$ $\nu(0d_{5/2})^3_{J=3/2}$ configuration. Measured limits on the cross sections of the $E^* = 0.0$- and 0.587-MeV states, determined from a multi-Gaussian fit implementing fixed centroid energies and widths, have been translated into spectroscopic factors and strengths (Table I). These values represent the upper limit for admixtures with allowed states of the same spins. An attempt to identify an $\ell = 0$ state(s) below $E^* \sim 1$, which would be unresolved from the 0.12- and 0.74-MeV peaks, was made by fitting the 0.12- and 0.74-MeV angular distributions with a combined $\ell = 0$ and $\ell = 2$ angular distribution. Only a small improvement to the fits was observed suggesting that there was little sensitivity to $\ell = 0$ strength, in particular to a 0^- state, below $E^* \sim 1$ MeV.

The peak at $E^* = 1.17(2)$ MeV has an angular distribution consistent with $\ell = 0$ [red-dashed line in Fig. 3(b)], making it either a part or the sum of the 1^-, 0^- doublet. A singular 0^- assignment is ruled out as its resulting spectroscopic factor dwarfs those of the 0.12-MeV and 0.74-MeV states by ~ 4, a highly unlikely scenario. Both scenarios for a lone 1^- state, and a doublet of states (0^- and 1^-), produce reasonable values of S and GS (Table I). Therefore, we suggest a state with $J^\pi = 1^-$ or states with $J^\pi = 0^-$ and 1^- at 1.17 MeV in excitation energy. The relatively large uncertainty in S (GS) is due to the sensitivity of the $\ell = 0$ DWBA calculations to optical-model parameters. Fits were also made to the 1.17-MeV angular distributions for pure $\ell = 1$ (blue-dotted line) or $\ell = 2$ (green-solid line) distributions, along with a composite $\ell = 0$ and $\ell = 2$ distribution, to investigate alternate spin assignments. The values from these fits are in Table I.

The counts at $E^* \sim 2.2$ MeV may comprise the excitations observed previously at $E^* = 2.21(2)$ and 2.42(2) MeV in the ^{18}O(^{7}Li,^{7}Be) reaction of Ref. [27]. The total observed yield for this state is $\sim$5% that of the 0.12-MeV state over the corresponding angle range. The strength observed in the neutron unbound excitation region between $\sim$2.8–8.7 MeV is possibly due to the $\nu 0d_{3/2}$ orbital.

The absolute scale for the measured S was determined by

$$N = \frac{\Sigma GS_{\ell=2} + \Sigma GS_{\ell=0}}{6.0}, \tag{2}$$

where the denominator of 6.0 is the number of neutron vacancies in the combined ($0d_{5/2}1s_{1/2}$) orbitals for $N = 10$, ^{17}N. It was assumed that the $\nu 0d_{3/2}$ orbital had little influence on the observed states, and that nearly all of the $0d_{5/2}$ and $1s_{1/2}$ strength was included in the sums. The 0.12-MeV and 0.74-MeV states made up the $\Sigma GS_{\ell=2}$. The 1.17-MeV state and an unknown 0^- state, surmised to have identical spectroscopic factors equal to that of the measured 1.17-MeV 1^- state, were included in $\Sigma GS_{\ell=0}$. The $\Sigma GS_{\ell=0}$ was also calculated considering that all of the $\ell = 0$ strength was contained in the area of the 1.17-MeV peak. The two normalizations differ by $\sim 9\%$, less than the other uncertainties. This normalization procedure was applied to the ^{18}O(d,p) data at 12.2 MeV/u and a value of $N = 1.46$ was found, in good agreement with the ^{17}N(d,p) value of $N = 1.49$. The uncertainty in the normalization is difficult to deduce due to, for example, unknown missing strength at higher excitation energies. We estimate $\pm 30\%$ uncertainty on N in this work. All quoted uncertainties in S and GS given explicitly are only relative and do not include this extra factor on their overall scale.

IV. DISCUSSION

The experimental neutron-adding spectroscopic strengths in ^{18}N are shown in Fig. 4(a) along with calculated strengths from three shell-model interactions in Figs. 4(b)–4(d). The shell-model calculations used the WBP [46] and WBT [46] interactions, as well as a more modern one [47], which combines interactions from the previous work of Refs. [48–50]. Here we refer to this new interaction as $V_{\rm MU}(p\text{-}sd)$. The WBP and WBT shell-model calculations had active nucleons in

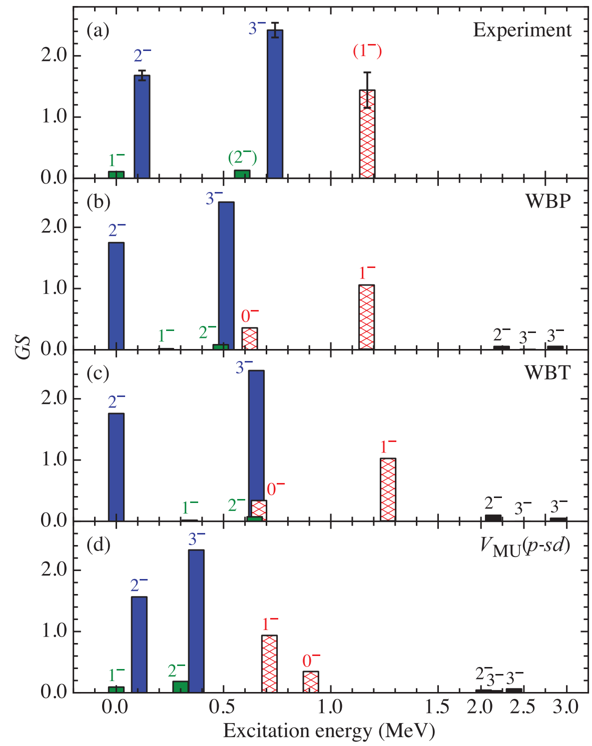

FIG. 4. (Color online) Experimental (a) and calculated (b)–(d) single-neutron spectroscopic strengths (note the nonlinear energy scale). Filled boxes represent $\ell = 2$ strength, hatched boxes $\ell = 0$, and the colors correspond to levels shown in Fig. 5. The experimental spectroscopic strengths for the 1^- ground state and the 0.587-MeV (2^-) state are upper limits, and relative uncertainties are shown by the black error bars. The measured state at 1.17 MeV labeled as (1^-) could also be a 0^-, 1^- $\ell = 0$ doublet.

the p-sd shells. Protons were restricted to the p shell, and neutrons were restricted to the sd shell assuming a fully occupied neutron p shell. The calculations were carried out with the shell-model code COSMO [51]. Calculations using the $V_{\rm MU}(p\text{-}sd)$ interaction were completed in a full p-sd model space, which can allow up to three nucleons to be excited from the p shell to the sd shell, however, only two-nucleon excitations were needed in the present study on the natural parity states. The specific details on the construction of the $V_{\rm MU}(p\text{-}sd)$ interaction can be found in Ref. [47].

Good agreement is found between the measured and calculated strengths. The $V_{\rm MU}(p\text{-}sd)$ reproduces the ground-state spin correctly, however, the splitting between each of the $\pi 0p_{1/2}$ partner states is compressed. The WBP (WBT) interaction reproduces the overall excitation energies better, getting reasonable values for the energy splitting between the 2^- and 3^- partners and the $\ell = 0$, 1^- state, while incorrectly calculating a smaller energy gap than observed between the 1^- and 2^-, ground and 0.587-MeV levels, respectively. An inversion of the $\ell = 0, 0^-$ and 1^- states is noticed between the $V_{\rm MU}(p\text{-}sd)$ interaction and the WBP (WBT) interaction, the latter of which agree with the ordering of the analogous levels in ^{16}N [43,44,47]. We note that the ^{18}N excitation energies are also reasonably described by the calculations of Ref. [28] using a modified Millener-Kurath interaction [52].

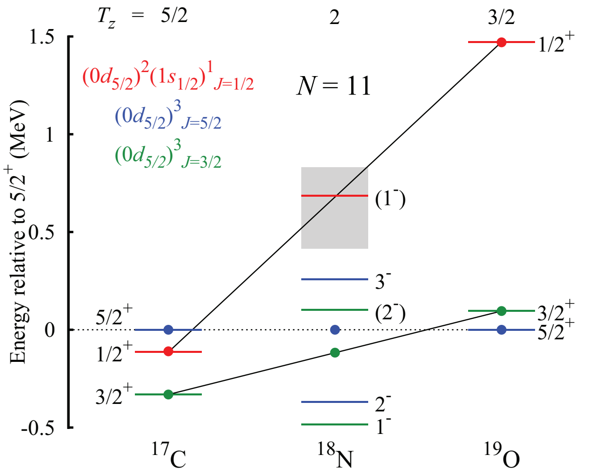

FIG. 5. (Color online) Lowest-lying experimental $J^\pi = 5/2^+$, $3/2^+$, and $1/2^+$ excitations in $N = 11$ nuclei. Level energy centroids are given by the round data points, and all levels are plotted relative to the $5/2^+$ centroid energies. The grey box represents the possible $1/2^+$ centroid energy range in ^{18}N. The solid black lines connect corresponding levels in ^{19}O to ^{17}C.

A plot, originated by Talmi and Unna [21] for the $N = 7$ and 9 isotones, is shown in Fig. 5 illustrating the evolution of the lowest-lying $5/2^+$, $3/2^+$ and $1/2^+$ energy centroids in the $N = 11$ isotones of carbon ($Z = 6$), nitrogen ($Z = 7$), and oxygen ($Z = 8$). The energies are plotted relative to the $5/2^+$ states for ^{19}O [2] and ^{17}C [20], while in ^{18}N the $S(2J_f + 1)$ weighted centroid of the 2^-_1 0.12- and 3^-_1 0.74-MeV states determined the $5/2^+$ energy. Only the 1^- state of the $\ell = 0$ component was observed. An estimated range for the $1/2^+$ centroid was determined using an excitation energy of the 0^- state ranging from 1 MeV below the 1^- energy ($E^* = 0.17$) to 0.5 MeV above it ($E^* = 1.67$ MeV). Only a $(2J_f + 1)$ weighting was applied in this case. The possible $\ell = 0$ centroid range under these assumptions covered $E^* = 0.900$–1.315 MeV and is shown by the gray box in Fig. 5. To calculate the $3/2^+$ centroid from the 1^-_1 and 2^-_2 states only a $(2J_f + 1)$ weighting was used as well. The level and centroid energies used in Fig. 5 are given in Table II.

One may expect that the centroids of the $3/2^+$ states (accessible in $N = 11$) based on the $(\nu d_{5/2})^3$ configuration, if containing only $d_{5/2}$ neutrons, would have a fixed energy relative to the $5/2^+$ states based on the same configuration. Indeed, shell-model calculations using the WBP interaction confining the valence neutrons to only the $0d_{5/2}$ orbital show a constant relative $3/2^+$ to $5/2^+$ energy for ^{19}O, ^{18}N, and ^{17}C (~0.6 MeV). The relative $3/2^+$ energy centroids *do*, however, change as a function of ΔZ, and the rate of change appears to be linear. This rate also appears to be approximately linear for the relative $1/2^+$ energies, indicating that contributions from the neutron $1s_{1/2}$ orbital impact the $3/2^+$ energies. The increase in influence of the neutron $1s_{1/2}$ orbital from ^{19}O to ^{17}C is in line with an increase in the $(1s_{1/2})^2$ ground-state admixture for the $N = 10$ isotones considering that the normalized strengths measured in ^{18}N (Table I) correspond to a $(1s_{1/2})^2$ admixture in the ^{17}N, $1/2^-$ ground state of $\lesssim 25\%$.

TABLE II. Excitation energies for the lowest $5/2^+$, $3/2^+$, and $1/2^+$ states. Uncertainties greater than 1 keV are explicitly given.

^AZ	Interaction	E^* (MeV)		
		$5/2^+$	$3/2^+$	$1/2^+$
^{17}C	Exp	0.330(4)	0.0	0.214(4)
	WBP	0.032	0.0	0.295
	WBT	0.0	0.078	0.268
	$V_{\mathrm{MU}}(p\text{-}sd)$	0.089	0.0	0.011
^{18}N	Exp	0.484(8)[a]	0.367[b]	0.900–1.315[b]
	WBP	0.299	0.391	1.031
	WBT	0.381	0.531	1.118
	$V_{\mathrm{MU}}(p\text{-}sd)$	0.266	0.188	0.766
^{19}O	Exp	0.0	0.096	1.472
	WBP	0.0	0.294	1.470
	WBT	0.0	0.294	1.470
	$V_{\mathrm{MU}}(p\text{-}sd)$	0.0	0.130	1.360

[a]Energy centroid, weighted by $S(2J_f + 1)$.
[b]Energy centroid (range), weighted by $(2J_f + 1)$.

This same value measured in ^{16}C is $\sim 30\%$ from a (d,p) measurement [53], and in ^{18}O there is a contribution of $\sim$12% as determined from ^{18}O(d,t) spectroscopic strengths [2]. The above trends for the relative $1/2^+$ to $5/2^+$ energies are also in agreement with the known reduction of the $N = 14$ shell gap between $Z = 8$ to 6 for other neutron numbers [13,21,54–56].

A linear fit to the $3/2^+$ data, having two free parameters (slope and offset), resulted in a slope of 0.22 MeV/ΔZ. A similar fit was carried out for the $1/2^+$ energies, including the centroid limits in ^{18}N (Table III). The range of the results for the $1/2^+$ energies contains the corresponding value for the $N = 9$ isotones of 0.81 MeV/ΔZ [2,21,22]. Using the relative $1/2^+$ energies from ^{19}O and ^{17}C, and assuming a linear dependence on isospin, we expect that the $1/2^+$ centroid in ^{18}N should lie at $E^* \approx 1.2$ MeV, nearly the same energy as the 1^-_2 state [$E^* = 1.17(2)$ MeV].

A plot of the type in Fig. 5 was investigated for calculated energies from the WBP [46], WBT [46], and $V_{\mathrm{MU}}(p\text{-}sd)$ [47] interactions. The resulting energies are given in Table II with their corresponding fitted linear slopes in Table III. None of the interactions were able to reproduce the individual relative energy differences, or their trends, in all three nuclei. However, the calculated results could be considered consistent within uncertainties (a few hundred keV). Interestingly, by plotting the WBP energies as a function of the calculated $\pi 0p_{1/2}$ occupancy instead of ΔZ, there was better agreement with the measured slopes.

TABLE III. Slopes from the fitted energy centroids.

	Slope (MeV/ΔZ)			
	Exp	WBP	WBT	$V_{\mathrm{MU}}(p\text{-}sd)$
$3/2^+$–$5/2^+$	0.22	0.16	0.11	0.11
$1/2^+$–$5/2^+$	0.75–0.85[a]	0.60	0.60	0.72

[a]Slope of 0.79 MeV/ΔZ from ^{17}C and ^{19}O energies only.

In summary, neutron configurations of some low-lying states in ^{18}N have been determined from the ^{17}N$(d,p)^{18}$N reaction at 13.6 MeV/u in inverse kinematics. Previously tentative spin assignments for the excited states at 0.12 MeV, $J^{\pi} = 2^{-}$ and 0.74 MeV, 3^{-}, are confirmed and a new state at 1.17(2) MeV, (1^{-}), has been uncovered. Spectroscopic factors and strengths from a DWBA analysis, using an internal normalization, are reproduced well by shell-model calculations using the WBP, WBT and $V_{\rm MU}(p\text{-}sd)$ interactions. The energy difference between the lowest $5/2^{+}$ and $3/2^{+}$ energy centroids seems to change linearly as a function of ΔZ in the $Z = 6-8$, $N = 11$ isotones.

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