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# Search for $1p$ Neutron Strength in $^{31}S$ by the Reaction $^{32}S(^3He,\alpha)^{31}S$†

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Levels of $^{31}S$ above $E_x = 4.5$ MeV have been studied with 18-MeV $^3He$ ions via the neutron-pickup reaction $^{32}S(^3He,\alpha)^{31}S$. The $\alpha$ particles were detected by position-sensitive counters placed along the focal plane of the spectrograph. The experimental energy resolution was 13–18 keV full width at half maximum and permitted the resolution of some multiplets that previously had been interpreted as single states. Strongly structured angular distributions for nine well-resolved $\alpha$-particle groups were obtained over the angular range $7.5 \leq \theta \leq 45°$. The $l$ values and spectroscopic factors for the transferred neutrons were extracted by comparison with distorted-wave calculations. The apparent absence of the bulk of the $1p$ neutron-pickup strength is discussed.

## I. INTRODUCTION

The high-resolution study of $^{31}S$ was stimulated by the report[1] of appreciable $l = 1$ spectroscopic strength in the reaction $^{32}S(d, ^3He)^{31}P$ at an excitation energy of 5.99 and 7.22 MeV in $^{31}P$. While the corresponding proton separation energy of about 16 MeV is very far from the separation energy of $44 \pm 7$ MeV suggested for the center of gravity of the $1p$ proton shell by the results of an $^{32}S(e,e'p)^{31}P$ experiment,[2] it would be in agreement with the proton separation energy expected for $1p_{1/2}$ protons from the systematics of proton-pickup reactions on $2s$-$1d$ nuclei.[3] Similarly, neutron-pickup reactions[4,5] in this region have shown relatively small $1p_{1/2}$ separation energies for target nuclei up to $^{29}Si$.[6] To date, however, there has been no evidence for $1p$ hole strength in neutron-pickup reactions from $^{30}Si$[7] and $^{32}S$.[4] In particular, the 7.05-MeV group in $^{31}S$, which is likely to be the analog of the 7.22-MeV state of $^{31}P$, was reported to be excited via $l = 2$ neutron transfer in the reaction $^{32}S(p,d)^{31}S$.[4] However, the published angular distribution of deuterons from the $^{32}S(p,d)$ experiment leading to the 7.05-MeV state in $^{31}S$ is not very structured and suffers from insufficient energy resolution. This leaves the $l = 2$ assignment uncertain and makes a high-resolution study of the angular distributions of excited states of $^{31}S$ very desirable.

The most recent information[8] on the levels of $^{31}S$ comes from studies of the reaction $^{32}S(^3He, \alpha)^{31}S$. Level energies had been obtained in magnetic-spectrograph measurements by Ajzenberg-Selove and Wiza[9] and Moss[8] up to an excitation of 7.5 and 7.3 MeV, respectively. Angular distribution for levels below an excitation of 4.6 and 5.2 MeV had been investigated by Fou and Zurmühle[10] and Moss,[8] respectively. These studies do not cover the interesting energy region where $1p$ pickup is expected in analogy to the proton data. Also, Moss's study does not include a distorted-wave Born-approximation (DWBA) analysis of the angular distributions, which will be essential for the establishment of $^{31}P$-$^{31}S$ analogy relations. Our aim was to obtain angular distributions from the reaction $^{32}S(^3He, \alpha)^{31}S$ in the energy range between 4.5 and 7.5 MeV and in particular find the $1p$ neutron-hole strength. While the $(^3He, \alpha)$ reaction gave fairly uncharacteristic angular distributions[10] for the first levels of $^{31}S$, it promised to be well suited in this particular case, since for slightly negative $Q$ values the angular momentum matching[11] is nearly perfect.

## II. EXPERIMENTAL PROCEDURE

$^3$He ions, accelerated to 18 MeV by the University of Pittsburgh Van de Graaff accelerator, were focused through a 1-mm-wide by 2-mm-high collimating slit onto a thin film of CdS deposited on a 10-$\mu$g/cm$^2$ carbon backing. This collimating slit, followed by an antiscattering slit, was positioned about 2 cm before the target in the scattering chamber. Elastically scattered $^3$He ions were continuously monitored by two NaI scintillation counters mounted at ±38° with respect to the beam direction. A detailed description of the spectrograph system and its typical operation has been given elsewhere.[12,13] The reaction $\alpha$ particles were momentum-analyzed by the Enge split-pole spectrograph and detected by an array of four position-sensitive counters mounted along the focal plane of this spectrograph. Each detector had a sensitive region 50 mm long and 8 mm wide. The 10-mm gaps between successive counters correspond to approximately 160-keV energy. Figure 1 shows the pulse-height ($XE$) spectrum for $\alpha$ particles observed at 17.5° in the first three counters. The peak-to-background ratio for the well-resolved 4.722- and 5.154-MeV peaks, for example, is nearly 80 to 1. Also observable is some energy nonlinearity, particularly near the detector edges, of about 6%.

In order to assign independent and more accurate excitation energies to the levels of $^{31}$S seen in this reaction, 50-$\mu$ Ilford K-1 nuclear emulsion plates were used to obtain additional spectra of the reaction $\alpha$ particles at $\theta = 17.5$ and 30°. The plates were scanned with 0.2-mm microscope field-width settings. Resolutions of the $\alpha$-particle groups from the plate and the counter runs at 17.5° were practically identical in this experiment. The energy resolution [full width at half maximum (FWHM)] of the detected $\alpha$-particle groups was 13 keV for the ground state but slowly became worse for the higher levels. The FWHM for the $\alpha$ particles leading to the 7.16-MeV excitation was 18 keV. The major contribution to the energy resolution, thus, came from the target thickness and the target nonuniformity effects. The angular distributions were measured in 2.5° steps for $7.5 \leq \theta \leq 20°$, and 5° steps for $25 \leq \theta \leq 45°$.

## III. EXPERIMENTAL RESULTS AND DISTORTED-WAVE CALCULATIONS

In Fig. 1 excitation energies for $^{31}$S are given in keV. The level energies of 4602, 5017, and 6716 keV, respectively, were not reported by Ajzenberg-Selove and Wiza,[9] but in part by Moss.[8] In Ref. 8 the 6990-7039-keV doublet was not resolved and several other levels were only marginally resolved; however, for most levels energy assignments of this study show excellent agreement with

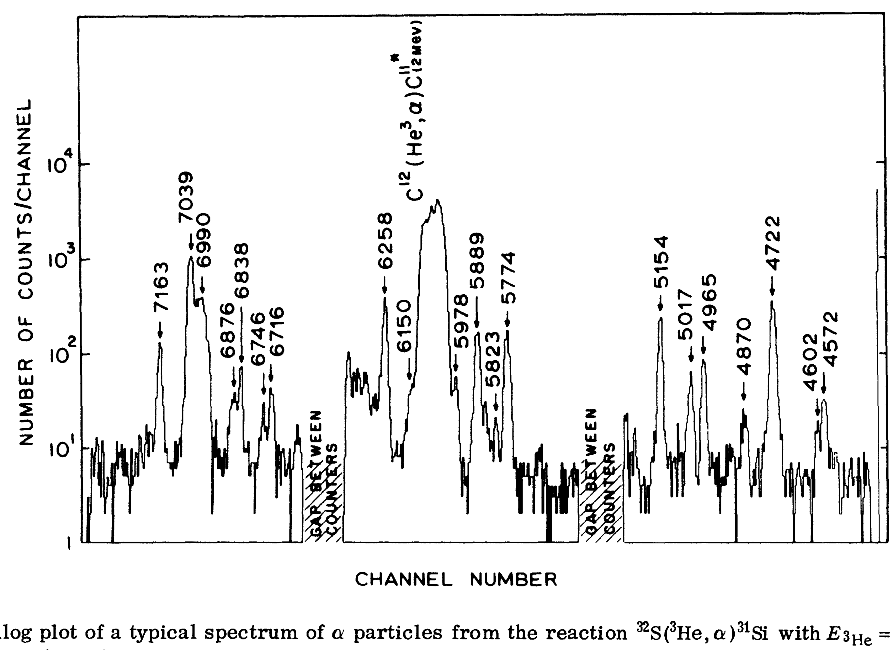


FIG. 1. Semilog plot of a typical spectrum of $\alpha$ particles from the reaction $^{32}S(^3He, \alpha)^{31}Si$ with $E_{^3He} = 18$ MeV taken at $\theta = 17.5°$ with the split-pole spectrograph using position-sensitive counters in the focal plane. The excitation energies in $^{31}$S for some of the $\alpha$ groups are labeled in keV. The typical dip between the 6990 and 7039 keV and the 6838- and 6876-keV levels in this spectrum is obscured by overlapping, weak contaminant lines. Angular distributions were obtained for the strongest nine states (numbered 12, 14, 15, 20, 25, 33, 34, and 35 in Table I).

TABLE I. A listing of excitation energies of levels of $^{31}$S from the present study in comparison with earlier work. Also given is the cross section at 17.5° unless a state is obscured by some impurity peak. The identification of a level by means of "state number" in Ref. 9 is retained. For any level reported in Ref. 9 which we do not see, an upper limit to the cross section at 17.5° is given. The accuracy in the relative energies of two nearby states is within 4 keV, whereas the absolute energy calibration is good to ~0.3% of $E_x$. The absolute differential cross sections are believed to be accurate within ±15%. The energies presented were obtained with nuclear-emulsion plates.

| Level No. | Present work $E_x$ (MeV ± $\Delta E$ [a]) | Present work $d\sigma/d\Omega$ at 17.5° ($\mu$b/sr) | $l_n$ | Ref. 9 $E_x$ (MeV ± keV) | Ref. 8 $E_x$ (MeV ± keV) |
|---|---|---|---|---|---|
| 0 | 0.0 | 1434 | | 0 | 0 |
| 1 | 1.245 | 1687 | | 1.242 ± 20 | 1.246 ± 10 |
| 2 | 2.230 | 6184 | | 2.232 ± 15 | 2.234 ± 10 |
| 3 | (3.075) | <120 | | ... | 3.075 ± 10 |
| 4 | 3.281 | 1170 | | 3.287 ± 15 | 3.286 ± 10 |
| 5 | 3.341 | 54 | | 3.359 ± 15 | 3.347 ± 10 |
| 6 | 3.434 | 180 | | 3.435 ± 15 | 3.437 ± 10 |
| 7 | 4.076 | Ref. b | | 4.085 ± 20 | 4.083 ± 12 |
| 8 | 4.200 | Ref. b | | 4.208 ± 25 | 4.209 ± 11 |
| 9 | 4.449 | 500 | | 4.451 ± 15 | 4.452 ± 9 |
| 10 | ... | <30 [c] | | 4.526 ± 15 | 4.522 ± 12 |
| 11 | 4.572 | 80 | | 4.582 ± 15 | 4.581 ± 9 |
| 11a | (4.602) | 35 | | ... | ... |
| 12 | 4.722 | 780 | 2 | 4.718 ± 15 | 4.717 ± 9 |
| 13 | 4.870 | 60 | | 4.85 ± 30 | 4.866 ± 9 |
| 14 | 4.965 | 175 | 1 | 4.976 ± 15 | 4.968 ± 10 |
| 14a | 5.017 | 142 | | ... | 5.026 ± 16 |
| 15 | 5.154 | 443 | 0 | (5.17 ± 30) | 5.154 ± 12 |
| 16 | ... | <20 | | 5.315 ± 15 | 5.301 ± 11 |
| 17 | ... | <30 | | 5.42 ± 30 | 5.440 ± 11 |
| 18 | 5.509 | 80 | | 5.52 ± 30 | 5.517 ± 15 |
| 19 | ... | <30 | | 5.697 ± 15 | (5.680 ± 10) |
| 20 | 5.774 | 394 | 2 | 5.792 ± 15 | 5.777 ± 11 |
| 21 | 5.823 | 50 | | 5.84 ± 30 | 5.824 ± 13 |
| 22 | 5.889 | 378 | 2 | 5.91 ± 30 | 5.893 ± 10 |
| 23 | 5.978 | 100 | | 5.994 ± 20 | 5.983 ± 13 |
| 24 | 6.150 | 105 ± 50 [d] | | 6.165 ± 25 | 6.154 ± 12 |
| 25 | 6.258 | 700 | 0 | 6.273 ± 20 | 6.268 ± 13 |
| 26 | ... | <100 | | 6.34 ± 30 | 6.348 ± 13 |
| 27 | ... | <100 | | 6.40 ± 30 | 6.39 ± 11 |
| 28 | ... | <20 | | 6.56 ± 30 | 6.540 ± 12 |
| 28a | ... | ... | | ... | (6.593 ± 15) |
| 29 | ... | <30 | | 6.63 ± 30 | (6.628 ± 15) |
| 29a | 6.716 | 90 | | ... | (6.711 ± 13) |
| 30 | 6.746 | 60 | | 6.763 ± 20 | 6.743 ± 13 |
| 31 | 6.838 | 127 | | (6.84 ± 30) | 6.834 ± 11 |
| 32 | 6.876 | 70 | | 6.896 ± 25 | 6.862 ± 12 |
| 33 | 6.990 | ~1000 | 0 | 6.99 ± 30 | ... |
| 34 | 7.039 | 2784 | 2 | 7.048 ± 20 | 7.036 ± 11 |
| 35 | 7.163 | 255 | 2 | 7.181 ± 20 | 7.161 ± 11 |

[a] $\Delta E = (4\text{ keV} + 0.003\, E_x)$.

[b] Obscured by $\alpha$ particles from $^{12}$C($^3$He, $\alpha$)$^{11}$C(g.s.) at 17.5°. $E_x$ for this state obtained from the 30° plate spectrum.

[c] For states such as number 10 where no excitation energy is given, we were not able to identify a level at an excitation energy corresponding to those of Refs. 8 and 9. Upper limit on the cross section is given in such cases.

[d] Partially obscured by $\alpha$ particles from $^{12}$C($^3$He, $\alpha$)$^{11}$C(2.0 MeV) at 17.5°.

Ref. 8. The energy assignments of Ref. 9 are systematically higher, but within the combined experimental errors.

Table I lists the excitation energies and $d\sigma/d\Omega$ at 17.5° for the states populated by the reaction $^{32}S(^{3}He, \alpha)^{31}S$. The excitation energies quoted were obtained from the two spectra obtained with nuclear-emulsion plates at $\theta = 17.5$ and 30°. We see a weakly populated state at 3075 keV which corresponds to the $3.06 \pm 0.03$-MeV state reported by Wesolowsky, Anderson, Hansen, Wong, and McClure.[14] Between $E_x = 7.16$ and 8.7 MeV, we do not see any state of $^{31}S$ excited by the ($^3$He, $\alpha$) reaction with an intensity equal to $\frac{1}{3}$ or higher of that of the 7163-keV state. We cannot, however, rule out the existence of some weakly populated levels of $^{31}S$ in this region.

Angular distributions for the nine stronger states that we investigated are shown in Fig. 2. The curves shown are predictions of the zero-range distorted-wave calculations using the code JULIE.[15] The optical-model parameters used in the DWBA calculations (see Table II) were taken from detailed analyses on the ($^3$He, $\alpha$) reaction on chromium isotopes at $E_{^3He} = 18$ MeV.[11] Additional calculations performed with $^3$He potential No. 2 and $\alpha$ potential No. 5 of Ref. 11 or with parameters used in the reaction $^{30}Si(^{3}He, \alpha)^{29}Si$ at 18 MeV[16] gave nearly identical fits. The fits are satisfactory and allow a unique determination of the $l$-transfer value. The 11° point of the 5.889-MeV angular distribution presents a minor problem, since it deviates from the typical shape of $l = 2$ angular distributions by several standard deviations. However, $l$ values other than 2, in particular an $l = 1$ assignment which might be suspected in analogy to the $^{32}S(d, {^3He})^{31}P$ (5.99 MeV) transition (see Table III) can be ruled out. To demonstrate this point the $l = 1$ angular distribution for the known 4.965-MeV level was plotted directly below the 5.889-MeV angular distribution in Fig. 2. DWBA calculations assuming both $2p$ (solid curve) and $1p$ (dashed curve) transfer for the 4.965-MeV state show a nearly vanishing difference in the shape of the angular distributions.

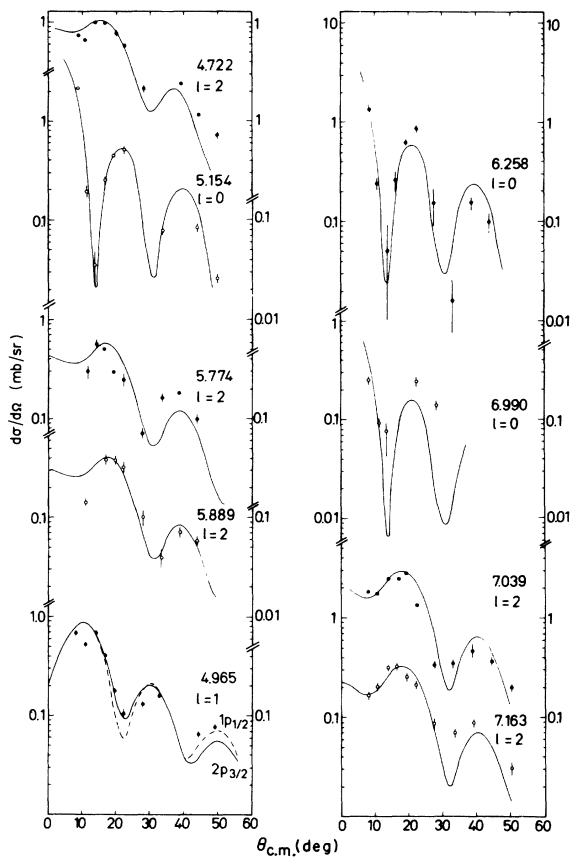


FIG. 2. Angular distributions for the transitions leading to some of the states in $^{31}P$ in the reaction $^{32}S(^{3}He, \alpha)$-$^{31}S$ with $E_{^3He} = 18$ MeV. The curves drawn are the DWBA predictions for the indicated $l$ transfers. The error bars for the data points are primarily due to statistics and uncertainties in the separation of close-lying levels. Systematic scale errors are not shown.

Spectroscopic factors were extracted with the normalization $\sigma_{\exp}(\theta) = 23\,C^2 S \sigma_{\rm DW}(\theta)$. The results based on the three parameter sets mentioned agree within 15%. In Table III we list the spectroscopic factors which were obtained with the parameters of Table II and which are close to the average of the three sets. Errors in addition to the 20% generally accepted for DWBA results are given whenever the normalization to the data is ambiguous.

Spectroscopic factors in parentheses are estimates based on the 17.5° spectrum (see Table I) for known $\frac{3}{2}^+$ and $\frac{5}{2}^+$ states in $^{31}S$. These estimates should be fairly reliable, since the corresponding c.m. angles belong to a smooth (near maximum) region of the $l_n = 2$ angular distribution. This is not so for the $l = 0$ ground-state ($l_n = 0$) transition where such an estimate was not made.

Compared to the shell-model sum rule for the $2s$-$1d$ strength, the absolute spectroscopic factors appear to be too large by about 30%, which is within the limits of the combined errors of DWBA calculations and absolute cross-section determinations. Therefore we included in Table III spectroscopic factors normalized such as to give a total of 8 for the $2s$-$1d$ strength. The ground state and the 4.076-MeV states are the only states which carry appreciable strengths that have been missed in our study. Their spectroscopic factors have been taken from the 15-MeV ($^3$He, $\alpha$) study of Ref. 10 after proper renormalization by comparison with the 1.245- and 2.230-MeV states.

## IV. DISCUSSION AND CONCLUSION

The results of several neutron-pickup reactions are compared in Table III. A complete survey of previous pickup studies concerned with energy levels below 4.5 MeV is contained in Ref. 8. One observes satisfactory agreement of the deduced $l_n$-transfer values where measurements overlap. The $l_n=2$ assignment to the 4.722-MeV level is now certain. The spin and parity assignments for levels above 5.2 MeV result from the present work. Also the spectroscopic factors from the $^{32}$S($p,d$)$^{31}$S study[4] agree reasonably well with the normalized ($^3$He, $\alpha$) values.

In addition, Table III contains the results from a low-resolution study of the reaction $^{32}$S($d$, $^3$He)$^{31}$P.[1] Energies, spins, and parities of the $^{31}$P levels have been taken from Wolf and Leighton[17] whenever a unique identification with the final states of the proton-pickup reaction was possible. We have lined up the $^{31}$P levels with their probable analogs in $^{31}$S. The arrangement is essentially based on the resulting close similarity of corresponding spectroscopic factors in proton- and neutron-pickup reactions. [The probably significant discrepancy in $C^2S$ for the first $\frac{5}{2}^+$ state indicates a violation of mirror symmetry which calls for a simultaneous ($d$, $t$) and ($d$, $^3$He) experiment on $^{32}$S.] The comparison implies that the ($d$, $^3$He) angular distributions leading to the 5.99- and 7.22-MeV states in $^{31}$P have to be considered as $l_p=2$ distributions, which seems possible with respect to the minor differences between $l_p=1$ and $l_p=2$ angular distributions discussed in Ref. 1. In fact, this reinterpretation gains support from preliminary results of a recent study[18] of the reaction $^{32}$S($d$, $^3$He)$^{31}$P at $E_d=52$ MeV with improved energy resolution (80 keV): The 5.99-MeV group exhibits a pure $l_p=2$ angular distribution. In the case of the 7.22-MeV group a weak $l_p=1$ admixture into a dominant $l_p=2$ angular distribution cannot be ruled out. Assuming $d_{5/2}$ pickup the spectroscopic factors for the 5.99- and 7.22-MeV states of $^{31}$P will change to $C^2S=0.17$ and 0.85, respectively. In consequence, the summed 2$s$-1$d$ strength in the ($d$, $^3$He) reaction[1] is increased from 4.1 to 5.2, which is reasonable considering the large energy range covered there. A further implication of this reinterpretation would be that the 7.22-MeV level in $^{31}$P which has been populated via $l_p=1$ stripping in the reaction $^{30}$Si($^3$He, $d$)$^{31}$P[17,19] is not identical to the 7.22-MeV level observed in the ($d$, $^3$He) study. Also the negative-parity assignment[1] to the ($\frac{3}{2}$) level[20] at 5.988 MeV in $^{31}$P has to be abandoned.

Thus there is no evidence for appreciable $l=1$ strength in neutron or in proton pickup from $^{32}$S. We observe only one $l_n=1$ transition at $E_x=4.965$ MeV in $^{31}$S. This level was not seen in the ($p$, $d$) reaction and only weakly excited in our study (see Table II). Its excitation is probably due to pickup from $(2p)^2$ admixtures in the ground state of $^{32}$S. This interpretation gains support from the fact that the probable analog level at $E_x=5.015$ MeV in $^{31}$P($J=\frac{3}{2}^-$) was not observed in the ($d$, $^3$He)$^{31}$P reaction, but strongly excited via $l_p=1$ stripping in the reaction $^{30}$Si($^3$He, $d$)$^{31}$P,[17,19] which demonstrates the dominant 2$p$ particle configuration of this state.

It may be argued that we could have missed the 1$p$ strength, since the ($^3$He, $\alpha$) reaction as an extreme surface reaction is not appropriate for the investigation of inner shells. However, the negative-parity states of $^{27}$Si which have been shown to be populated via 1$p$ pickup in the reaction $^{28}$Si($p$, $d$)$^{27}$Si by Kozub[4] are equally strongly excited in a more recent $^{28}$Si($^3$He, $\alpha$)$^{27}$Si study.[21] In addition, the ($d$, $^3$He) reaction which has yielded the results on proton pickup from the 1$p$ shell is also known to be a surface reaction which probes the tail of the bound-state wave function.

States of $^{31}$S are proton unstable above 6.1 MeV. For levels sufficiently above this threshold this may lead to a line broadening which if pronounced could make it hard to discriminate the lines against the background. However, within our energy resolution we do not notice any broadening for the 2$s$ and 1$d$ hole states observed up to 7.2 MeV, and there is little reason to suspect that this is very different for states with dominant 1$p$ hole configurations.

A different explanation for the nonobservation of the 1$p$ hole strength near 7 MeV might be sought in fractionation due to mixing with 2$p$-particle configurations as has been observed in the reaction

TABLE II. Optical-model parameters used for the distorted-wave analyses.

| | $V$ (MeV) | $r_0$ (fm) | $r_{0C}$ (fm) | $a_s$ (fm) | $W$ (MeV) | $r_{0I}$ (fm) | $a_I$ (fm) | $V_{so}$ (MeV) |
|---|---|---|---|---|---|---|---|---|
| $^3$He | 133.0 | 1.08 | 1.3 | 0.8 | 18.2 | 1.63 | 0.754 | 6.0 |
| $^4$He | 183.7 | 1.4 | 1.3 | 0.564 | 26.6 | 1.4 | 0.564 | ... |
| Bound neutron | ... | 1.25 | 1.25 | 0.65 | ... | ... | $\lambda=25$ | |

$^{29}Si(p, d)^{28}Si$ (Ref. 6). In fact, four $2p$ particle states have been located via the ($^3He$, $d$) reaction in the mirror nucleus $^{31}P$ at excitation energies between 6.4 and 7.2 MeV. Adding the two lowest (unperturbed) $1p$ hole states predicted by the systematics[22] of $1p$ hole states in odd-$A$ nuclei, one might expect to find a $1p$ strength of $C^2S \approx 2$ distributed over not more than six states.

The $^{31}S$ groups visible in Fig. 1 for which angular distributions were not extracted are all weaker than the peak for the ($2p$) level at 4965 keV, which has $C^2S(2p) = 0.06$. Even if the extreme assumption is made that all these levels are $l = 1$ states with significant $1p$ admixtures, their total $1p$ strength would be almost an order of magnitude smaller than the expected strength of $C^2S \approx 2$. Previous investigations of $1p$ hole states in the $2s$-$1d$ shell give every reason to believe that spectroscopic factors from DWBA analyses are correct within at least a factor of 2. Therefore we conclude that the $1p_{(1/2)}$ neutron hole states are excited by more than 7.4 MeV in $^{31}S$. As mentioned above, this conclusion throws considerable doubt on the former $1p$ assignment[1] to proton hole states in the mirror nucleus $^{31}P$. It is, however, fully consistent with the results from a recent $^{32}S(d, ^3He)$-$^{31}P$ study with improved energy resolution.[18]

After completion of our ($He^3$, $\alpha$) study the analysis of the recent ($d$, $^3He$) study revealed the existence of a $l_p = 1$ transition to a level at $E_x = 7.98 \pm 0.02$ MeV in $^{31}P$ which carries an essential fraction of the expected $1p_{1/2}$ strength. The emulsion-

TABLE III. Comparison of results for neutron and proton pickup on $^{32}S$.

| $E_x$ (MeV) in $^{31}S$ (Present work) | $J^\pi$ ($T = \frac{1}{2}$) (Ref. a) | ($p, d$) (33.6 MeV) (Ref. 4) $l_n$ | $C^2S$ | ($^3He$, $\alpha$) (12 MeV) (Ref. 8) $l_n$ | ($^3He$, $\alpha$) (18 MeV) (Present work) $l_n$ | $C^2S$ [b] | $C^2S$ norm. [c] | $E_x$ (MeV) in $^{31}P$ (Ref. 17) | $J^\pi$ ($T = \frac{1}{2}$) (Ref. 17) | ($d$, $^3He$) (Ref. 1) $l_p$ | $C^2S$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.0 | $\frac{1}{2}^+$ | 0 | 1.04 | 0 | | ... | (0.7) [d] | 0.0 | $\frac{1}{2}^+$ | 0 | 1.10 |
| 1.245 | $\frac{3}{2}^+$ | 2 | 0.94 | | | (1.25) | (0.95) | 1.266 | $\frac{3}{2}^+$ | 2 | 0.98 [e] |
| 2.230 | $\frac{5}{2}^+$ | 2 | 2.77 | | | (2.95) | (2.25) | 2.234 | $\frac{5}{2}^+$ | 2 | 1.84 [e] |
| 3.075 | $\frac{1}{2}^+$ | | | 0 | | | | 3.134 | $\frac{1}{2}^+$ | 0 | 0.11 [e] |
| 3.281 | $\frac{5}{2}^+$ | 2 | 0.73 | 2 | | (0.54) | (0.41) | 3.295 | $\frac{5}{2}^+$ | 2 | 0.53 |
| 3.434 | $\frac{3}{2}^{(+)}$ | | | (2) | | | | 3.506 | $\frac{3}{2}^+$ | | |
| 4.076 | $(\frac{5}{2})^+$ | 2 | 0.86 | (2) | | ... | (0.85) [d] | 4.191 | $\frac{5}{2}^+$ | 2 | 0.53 |
| 4.449 | $(\frac{5}{2}, \frac{7}{2})^-$ | | | 3 | | | | 4.443 | $\frac{7}{2}^-$ | | |
| 4.522 [f] | $(\frac{3}{2}, \frac{5}{2})^+$ | | | 2 | | | | 4.592 | $\frac{3}{2}^+$ | | |
| 4.722 | $(\frac{3}{2}, \frac{5}{2})^+$ | (0) | ... | 2, (3) | 2 | 0.45 | 0.34 | 4.783 | $\frac{5}{2}^+$ | 2 | 0.23 |
| 4.870 | | | | (1) | | | | | | | |
| 4.965 | $(\frac{3}{2}, \frac{1}{2})^-$ | | | 1 | 1 | 0.06 [g] | 0.045 | 5.015 | $\frac{3}{2}^-(\frac{1}{2})^-$ | | |
| 5.154 | $\frac{1}{2}^+$ | | | 0 | 0 | 0.32 | 0.24 | 5.253 | $\frac{1}{2}^+$ | 0 | 0.20 |
| 5.774 | $(\frac{3}{2}, \frac{5}{2})^+$ | | | | 2 | 0.27 | 0.21 | | | | |
| 5.889 | $(\frac{3}{2}, \frac{5}{2})^+$ | | | | 2 | 0.20 | 0.15 | 5.99 [h] | | 1 | 0.5 ± 0.2 [i] |
| 6.258 | $\frac{1}{2}^+$ | | | | 0 | 0.22 ± 0.06 | 0.17 | 6.41 ± 0.06 [h] | | 0 | 0.32 |
| 6.990 | $\frac{1}{2}^+$ | | | | 0 | 0.05 ± 0.02 | 0.04 | 6.9 ± 0.2 [h] | | | Weak |
| 7.039 | $\frac{5}{2}^+(\frac{3}{2})^+$ | 2 | 1.00 | | 2 | 1.85 | 1.40 | 7.22 [h] | | 1 | 1.4 ± 0.4 [i] |
| 7.163 | $(\frac{3}{2}, \frac{5}{2})^+$ | | | | 2 | 0.21 | 0.16 | | | | |

[a] References 8 and 20 for $E_x < 5.2$ MeV; present work for $E_x > 5.2$ MeV.
[b] $d_{5/2}$ transfer assumed for $l_n = 2$ except for $E_x = 1.245$ MeV. $C^2S(1d_{3/2})$ are about 50% larger than $C^2S(1d_{5/2})$.
[c] Normalized to give a total $s$-$d$ strength of about 8.
[d] See Ref. 10.
[e] See Ref. 18.
[f] See Ref. 8.
[g] $C^2S = 0.29$ if $1p_{1/2}$ transfer is assumed.
[h] See Ref. 1.
[i] $C^2S = 0.17$ for $E_x = 5.99$ MeV and $C^2S = 0.85$ for $E_x = 7.22$ MeV if $l_p = 2$ ($1d_{5/2}$) is assumed (Ref. 18).

plate spectra from the present reaction $^{32}$S($^3$He, $\alpha$)-$^{31}$S show a prominent group at $E_x = 7.74$ MeV in $^{31}$S which exhibits a line width about 50% larger than the nearby lower-lying peaks. We consider this group as a good candidate for the analog 1$p$ neutron hole state. If this expectation is confirmed by future investigations the present failure to observe strong $l = 1$ transitions in the predicted energy range would not signal a breakdown of our understanding[3, 22] of 1$p$ hole states in 2$s$-1$d$ shell nuclei but could be coped with by a 10% change of the parameters in the effective interaction used in Ref. 3. The tremendous difference of 1$p$ separation energies measured in ($e$, $e'p$) experiments[2] on one hand and pickup experiments from $^{32}$S on the other would still persist.

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# Reaction $^{86}$Kr($d$, $^3$He)$^{85}$Br†

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The ground state and first four excited states of $^{85}$Br observed in the reaction $^{86}$Kr($d$, $^3$He)-$^{85}$Br at 0.0, 0.348, 1.169, 1.792, and 2.310 MeV have been assigned spins and parities of $\frac{3}{2}^-$, $\frac{5}{2}^-$, $(\frac{3}{2})^-$, $(\frac{1}{2})^-$, and $(\frac{9}{2}^+)$, respectively.

## INTRODUCTION

The major shell closure for neutrons at $N = 50$ is a favorable region in which to study proton-transfer reactions. Our knowledge of the proton single-particle levels in the lower proton region of the $N = 50$ shell is not adequate. Since $^{86}$Kr has eight protons outside the major closed shell at $Z = 28$, we have applied simple pairing theory to extract the single-particle energies from the data of the