W(p,t) reactions. II. Odd target

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Data for the $^{183}W(p,t)^{181}W$ reaction are presented. States corresponding to the coupling of the odd neutron to collective excitations of the even core are identified and used to test the microscopic structure of these collective excitations. In particular, the proposed nature of the pairing isomers observed in the neighboring even nuclei is confirmed. Information concerning the previously observed anomalous population of 2^+ states in this mass region is also presented.

[NUCLEAR REACTIONS $^{183}W(p,t)$, $E_p=21$ MeV; measured $\sigma(E_t,\Theta)$. ^{181}W deduced levels, L, π, J. Nuclear structure analysis.]

I. INTRODUCTION

In this, the second of our papers on $W(p,t)$ reactions, we present and discuss the results for the single stable odd W isotope ^{183}W. The spectroscopic information obtainable from two-neutron transfer reactions on odd targets is generally rather limited. However, in this particular case we are able to glean a considerable amount of structural information, particularly from the effect of the coupling of the odd neutron to collective excitations of the even core. We are thus able to test some of the hypotheses presented in the preceding paper concerning the even targets,[1] and in the case of excited 2^+ states, shed new light on the origin of some previously unexplained anomalies.

II. EXPERIMENTAL METHOD

The details of the experimental method are identical to those presented in Ref. 1. The target consisted of ~70 $\mu gm/cm^2$ of WO_3 enriched to 90% in ^{183}W deposited on a 20 $\mu gm/cm^2$ C backing. Other isotopes present in the target were ^{182}W (3.5%), ^{184}W (5.6%), and ^{180}W (1.1%). The absolute cross sections were obtained from the $^{nat}W(p,t)$ experiment as described in Ref. 1.

III. EXPERIMENTAL RESULTS

A spectrum taken at a laboratory angle of 20° is shown in Fig. 1—note the reduction by a factor of 5 for peaks 3–12. The overall resolution is ~20 keV. Peaks identified as belonging to ^{181}W are numbered and also their measured excitation energies listed in Table I in comparison with previous results.[2,3] Angular distributions for some of the stronger peaks are shown in Fig. 2.

The most prominent peak in the spectrum (No. 5) has a distinct $L=0$ angular distribution. This transition presumably leads to the $J^\pi=\frac{1}{2}^-$ bandhead of the band built on the $\frac{1}{2}^-[510]$ Nilsson orbit, since the odd neutron of the ^{183}W ground state has been assigned to that single-particle state.[4] Based on published level schemes, we expect that this $\frac{1}{2}^-$ state at 458 keV would not be completely resolved from the $\frac{3}{2}^-$ state at 450 keV and barely resolved from the $\frac{7}{2}^-$ state at 476 keV. The deep minima in the angular distribution, however, unambiguously identify this transition as $L=0$ and not $L=2$ or 4, which would be required for the $\frac{3}{2}^-$ and $\frac{7}{2}^-$ states, respectively. The maximum contribution from these other states can be estimated to be 5 $\mu b/sr$ of the maximum cross section of 280 $\mu b/sr$ for this peak.

Besides the $L=0$ transition to the $J^\pi=\frac{1}{2}^-$ bandhead of the $K^\pi=\frac{1}{2}^-$ band, $L=2$ transitions to the $\frac{3}{2}^-$ and $\frac{5}{2}^-$ members of this band are also observed, being peaks Nos. 7 and 8, respectively.

The above three transitions correspond to the states formed by the coupling of the odd neutron to the 0^+ and 2^+ members of the ground-state rotational band of the even score. Similarly, strong transitions corresponding to the gamma-vibrational and excited 0^+ modes should also be observable. Assuming that the coupling between the $\frac{1}{2}^-$ neutron and the gamma-vibrational degree of freedom is weak, we would expect to see two transitions, to $\frac{3}{2}^-$ and $\frac{5}{2}^-$ states, corresponding to the

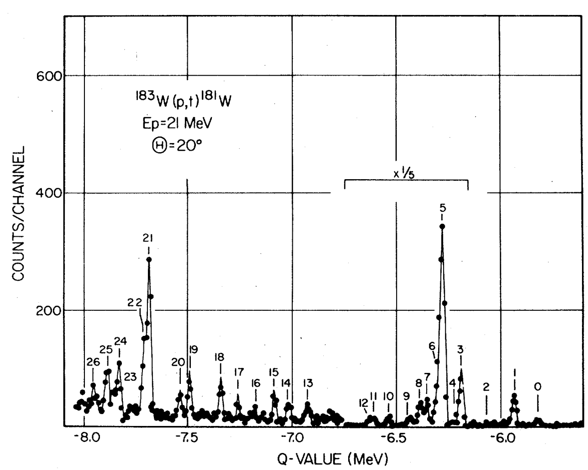

FIG. 1. Spectrum of the $^{183}W(p,t)^{181}W$ reaction at 21 MeV bombarding energy and a laboratory angle of 20°.

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TABLE I. Levels populated in $^{183}W(p,t)^{181}W$.

State number	$J^{\pi\,a}$	Present [b]	Previous [a]	$(d\sigma/d\Omega)_{max}$ (μb/sr)
0	$\frac{9}{2}^+$	0	0	
1	$\frac{11}{2}^+$		113	
2	$\frac{13}{2}^+$		250	
3	$\frac{5}{2}^-$	365	366	70
4	$\{\frac{1}{2}^-, \frac{7}{2}^-$	409 D	{385, 409	7
5	$\{\frac{3}{2}^-, \frac{1}{2}^-$	454	{450, 458	280
6	$\{\frac{7}{2}^-, \frac{5}{2}^-$	489	{476, 488	72
7	$\{\frac{9}{2}^-, \frac{3}{2}^-$	531	{527, 529	34
8	$\frac{5}{2}^-$	560	560	63
9	$\frac{9}{2}^-$	610	~611	11
10		714	715	13
11		784		8
12	$\frac{5}{2}^-$	807	807	11
13		1093		7
14		1193		8
15		1262		6
16		1377		7
17		1437		6
18		1518		8
19		1667		14
20		1712		7
21	$\frac{1}{2}^{-\,c}$	1864		44
22		1892		35
23		1945		5
24		2015		12
25		2034		8
26		2067		17

[a] From Refs. 2, 3, and 4, unless otherwise indicated.
[b] Calculated assuming $\frac{5}{2}^-$ state at 365 keV excitation, error ± 5 keV.
[c] Assignment this work.
[d] Doublet.

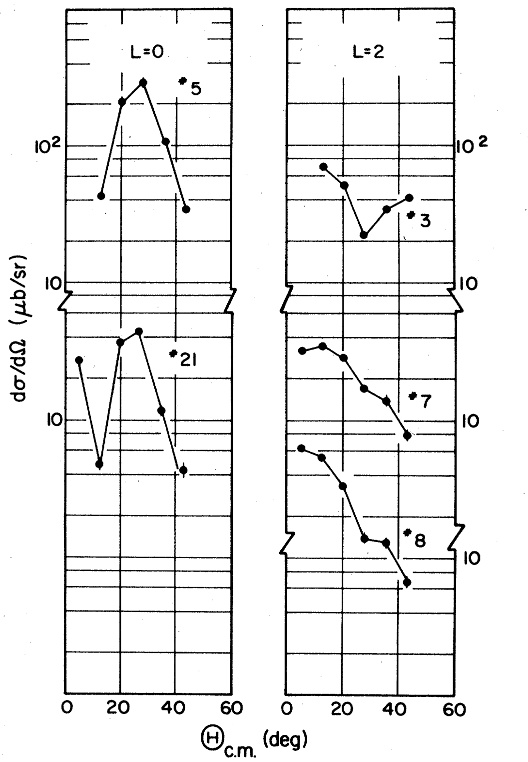

FIG. 2. Angular distributions for some of the stronger transitions.

$L=2$ strength in the even target case. These should occur at about 1 MeV above the $\frac{1}{2}^-[510]$ state, i.e., at an energy roughly corresponding to the excitation energy of this mode in the even nucleus. No such transitions are seen. Instead, a strong $L=2$ transition to the $\frac{5}{2}^-$ state at 365 keV (No. 3) is seen—the Nilsson assignment of this state being $\frac{5}{2}^-[512]$. The implications of this observation will be discussed in Sec. IV.

A strong $L=0$ transition is found at an excitation energy of 1864 keV (No. 21) and is interpreted as arising from a state formed by the coupling of the odd neutron to the excited 0^+ state in ^{180}W at 1516 keV. There is a barely resolved state (No. 22) at an excitation energy of 1892 keV, but this was easily separated by standard peak fitting procedures.

IV. DISCUSSION

A. $L=0$ transitions

As discussed above, strong $L=0$ transitions are observed to states at 454 and 1864 keV. These correspond to the strong $L=0$ transitions observed in the (p,t) reaction on the even core, but with an extra neutron in Nilsson orbit $\frac{1}{2}^-[510]$ coupled to the initial and final states. This supposition is strengthened by the near equality of the Q values for these two transitions and the $^{182}W(p,t)^{180}W$(g.s.) and $^{182}W(p,t)^{180}W$ (1516 keV) transitions, respectively. These two states therefore become very important in our understanding of the underlying microstructure in the even target cases. Microscopically, the 454 keV transition corresponds identically to the ^{182}W$(p,t)^{180}$W(g.s.) transition, but with one important difference. The odd particle occupies one of the orbits from which a pair of neutrons is picked up in the even case. This orbit is then said to be "blocked" and the odd target $L=0$ cross section reduced by the appropriate amount. Experimentally, the ^{182}W$(p,t)^{180}$W(g.s.) transition has a maximum cross section of 500 μb/sr, whereas the present 454 keV transition has only 280 μb/sr—a 40% decrease. This number can then be used as a sensitive test of the microscopic form factors used to describe the even target ground-state strengths. A calculation to do just this was performed as follows.

The standard set of single-particle levels described in the previous paper was used to generate a BCS form factor which was then used in conjunction with the distorted-wave Born approximation (DWBA) code DWUCK[7] to calculate the strength of the ^{182}W$(p,t)^{180}$W(g.s.) transition. Precisely the same calculation was then performed, except that the $\frac{1}{2}^-[510]$ level was effectively blocked by artificially respecifying its binding energy so as to place that level well above the Fermi surface. Its occupancy was then such that it contributed negligibly to the final cross section. This calculation predicts a blocking effect of 45%, in reasonable agreement with experiment. The calculated values of Δ did not, however, agree well with the experimental values of P_N for either ^{181}W or ^{183}W, reflecting not unexpected deficiencies in the single-particle spectrum used. The calculation was repeated using a value of the pairing matrix element chosen so that $\Delta = P_N$. A blocking of 36% was predicted, again in good agreement with the experimental value of 40%.

For the 1864 keV $L=0$ transition, it was proposed in Refs. 1 and 5 that the 1516 keV 0^+ state in ^{180}W as well as 0^+ states at 997 in ^{178}W and near 2600 keV in ^{182}W, arise from pair pickup from a group of orbitals below and decoupled from the Fermi surfaces of the target nuclei. An important consequence of this picture is that in the odd target case, not only should there also exist an analogous $L=0$ transition, but also that, owing to the decoupling, this transition should not exhibit blocking. As we have seen, the transition corresponding to the even ground-state transition is blocked by $\approx$40%—the results for the excited state transition do not show this effect. The maximum cross section for ^{182}W$(p,t)^{180}$W(1516 keV) is 36 μb/sr, the 1864 keV ^{183}W$(p,t)^{181}$W transition has 44 μb/sr in agreement with expectations. These results are illustrated in Fig. 3.

B. $L = 2$ transitions

Two $L=3$ transitions are observed corresponding to the $\frac{3}{2}^-$ and $\frac{5}{2}^-$ states formed by the coupling of the odd neutron to the 2^+ member of the even core ground-state rotational band. The angular distributions for these transitions, the $L=0$ transition to the 454 keV $\frac{1}{2}^-$ state and the ^{182}W$(p,t)^{180}$W transitions to the 0^+ and 2^+ members of the ground band are shown in Fig. 4. As discussed above,

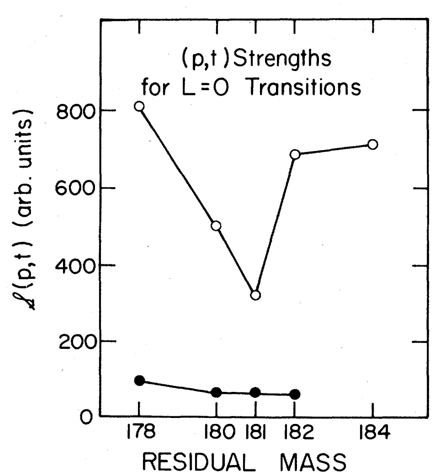

FIG. 3. Strengths for $L=0$ transitions throughout the W isotopes. This illustrates the blocking of the ground-state strength (open circles) and the constant strength for the excited $L=0$ transitions (closed circles).

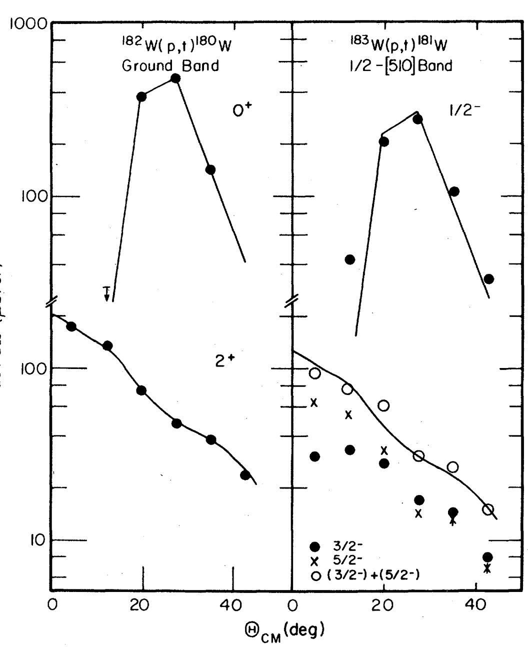

FIG. 4. Comparison of angular distributions for the transitions to members of the ground band of ^{180}W and the corresponding states in ^{181}W. The shapes of the ^{180}W transitions are shown superimposed on the ^{181}W data.

apart from the blocking effect, the $L=0$ shapes are identical and we expect a similar result for the $L=2$ transitions. We see that the summed strength of the two odd target transitions closely resembles the even target data and shows a similar reduction in strength to the $L=0$ case. The splitting of the summed strength is also of interest. In the adiabatic limit, the cross sections for the two transitions should follow the rule

$$\frac{\sigma(\theta)(\frac{3}{2}^-)}{\sigma(\theta)(\frac{5}{2}^-)}=\frac{2}{3}$$

at all angles. Experimentally we find that whereas the ratio of the integrated yields to these two states closely equals the expected value (182 : 184 = 2.15 : 3), the shapes of the two angular distributions are quite different, especially at forward angles. The origin of this discrepancy can be traced to differences between the multiple step routes populating the two states. Simply, the multiple step route involving quadrupole inelastic excitation and quadrupole pair transfer enters with different phases for the two final states—resulting in different angular distribution shapes. A detailed study of this phenomenon would surely prove rewarding.

Finally, we address the case of the $L=2$ strength corresponding to the gamma-vibrational state in the even nuclei. As mentioned above, no strength was observed in the excitation region expected. A very strong transition was, however, observed to a $\frac{5}{2}^-$ state at 365 keV. This state has been associated with the $\frac{5}{2}^-$[512] Nilsson orbit, and calculations show that of all the single-particle orbital combinations with $J^\pi K=2^+2$ which are close to the Fermi surface, the coupling to this orbit with the $\frac{1}{2}^-$[510] orbit has one of the stronger intrinsic two-nucleon pickup strengths. In fact, as can be seen in Table II, only for two-particle configurations have any significant gamma-vibrational strength—thus casting doubt on the collective nature of this state as seen in two-particle transfer. The amount of gamma-vibrational strength seen in any nucleus will therefore depend strongly on the position of the Fermi surface relative to these single-particle orbitals, and it is therefore perhaps not surprising that anomalies such as that reported by Casten and Garrett[6] for the ^{182}W$(t,p)^{184}$W reaction occur. What is perhaps more surprising is that these anomalies are not more frequent. We therefore understand the present result and the trend of gamma-vibrational strength in the even nuclei as arising from a sensitivity to a few single-particle configurations which carry most of the relevant two-particle transfer strength.

TABLE II. $J^\pi K=2^+2$ pickup strengths.

Configuration	$\left(\frac{d\sigma}{d\Omega}\right)^a$ 42.5° (μb/sr)
$\frac{1}{2}$[510]⊗$\frac{3}{2}$[512]	660
⊗$\frac{5}{2}$[512]	164
$\frac{1}{2}$[521]⊗$\frac{3}{2}$[512]	10
⊗$\frac{5}{2}$[512]	147
$\frac{3}{2}$[512]⊗$\frac{7}{2}$[503]	334
⊗$\frac{7}{2}$[514]	3
$\frac{5}{2}$[512]⊗$\frac{9}{2}$[505]	15
$\frac{1}{2}$[660]⊗$\frac{5}{2}$[642]	1
$\frac{3}{2}$[651]⊗$\frac{7}{2}$[633]	1
$\frac{5}{2}$[642]⊗$\frac{7}{2}$[624]	8
$\frac{7}{2}$[633]⊗$\frac{11}{2}$[615]	2

[a]Calculated using Nilsson wave functions for $\beta_2=0.30$ and optical model parameters as quoted in Ref. 1.

V. SUMMARY AND CONCLUSIONS

A study of the ^{183}W$(p,t)^{181}$W reaction has led to the identification of transitions to states corresponding to the coupling of the odd neutron to collective excitations of the even core. Specifically these are $L=0$ and $L=2$ transitions corresponding to the 0^+ and 2^+ members of the ground-state rotational band and an $L=0$ transition corresponding to the lowest excited 0^+ state of the even core. The former transitions show a blocking effect while the latter does not, consistent with the assumed microscopic structure of both. The failure to observe $L=2$ strength corresponding to the gamma vibration of the even core is traced to the dominance of a few single-particle configurations in the excitation of this mode in two-particle transfer reactions. Some interesting multistep effects have also been pointed out in the case of the $L=2$ transitions corresponding to the 2^+ excitation of the core.

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