$Ir(\vec{t},\alpha)Os$ reaction and implications for tests of supersymmetries

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The $(\vec{t},\alpha)$ reactions have been studied on $^{191,193}Ir$ targets. The analyzing power to the 2_2^+ state in ^{192}Os does not indicate single step $d_{3/2}$ proton transfer. Implications of this result for the theoretical interpretation of earlier $(d,{}^3He)$ measurements in terms of supersymmetries are discussed.

Several years ago Iachello suggested[1] that dynamical supersymmetries within the framework of the interacting boson approximation (IBA) model may exist in heavy nuclei. Since then there have been many studies[2–7] to test the predictions of this supersymmetry scheme using single-nucleon transfer reactions. These studies have been of two types: even-mass targets, odd-mass final nuclei studied with polarized and unpolarized projectiles; and odd-mass targets, even-mass final nuclei which have only been studied with unpolarized projectiles. Agreement between the theoretical predictions and measured spectroscopic factors for the first type has been rather good for $^{191,193}Ir$ and ^{195}Pt final nuclei.[2–4] However, the agreement between theory and experiment for the odd-mass target measurements has been rather poor for all of these studies.[5–7] In particular, the transfer to the 2_2^+ state of the final nucleus, a forbidden transition in the supersymmetry scheme, is as strong as the allowed transition to the 2_1^+ state.

The most extensive tests involving one particle transfer have been of the U(6/4) supersymmetry[1,8,9] which arises when the core has a good O(6) boson structure,[10] the valence particle has $j=\frac{3}{2}$, and a particular form of the boson-fermion interaction is present. The even-mass Os and Pt nuclei have been well characterized[11] by the O(6) limiting symmetry of the IBA. The U(6/4) model has been quite successful[8,9,12,13] in describing the energy and γ-ray deexcitation schemes of $^{191,193}Ir$ and $^{193,197}Au$, which have $\frac{3}{2}^+$ ground states. Given this good agreement between theory and experiment for the energy levels and the single particle properties of the odd-mass nuclei, why is there such poor agreement between theory and experiment for the single particle character of the even-mass nuclei?

To limit the number of possible sources of this discrepancy, we have recently studied the proton pickup reactions on $^{191,193}Ir$ targets using polarized beams. By measuring cross sections and analyzing powers, it was hoped to characterize better the single particle configuration that was transferred and to provide more information on the reaction mechanism.

The $(\vec{t},\alpha)$ reaction was studied on enriched targets of $^{191,193}Ir$ at the Los Alamos Van de Graaff accelerator facility using the polarized triton source.[14] The reaction α particles were momentum analyzed in a Q3D spectrometer and detected with a helical proportional chamber in the focal plane.[15] Data were taken at two angles, 35° and 40°, with spin "up" and spin "down" spectra taken sequentially. The spectra for the $^{191}Ir(\vec{t},\alpha)$ and $^{193}Ir(\vec{t},\alpha)$ reactions at 40° are shown in Figs. 1 and 2, respectively. The detection geometry is such that, in the Bäsel convention, positive analyzing powers yield more counts in the spin down mode than in the spin up mode. The polarization of the triton beam was typically 0.65; the resolution was 18 keV (FWHM). The measured cross sections and analyzing powers to the low-lying states and strongly populated 4_3^+ states are given in Table I. For a single step reaction process, negative analyzing powers would indicate $j=l-\frac{1}{2}$ transfer, positive analyzing powers $j=l+\frac{1}{2}$ transfer, and near zero values would indicate $s_{1/2}$ transfer.

Single-step distorted wave calculations were made with the computer code DWUCK4 (Ref. 18) and with the optical model parameters used in an earlier study of the $Pt(\vec{t},\alpha)Ir$ reactions.[3] As was noted in an earlier $Ir(d,{}^3He)$ measurement[6] to the same final nuclei, where more complete angular distributions were obtained, the transitions to the 2_1^+ and 2_2^+ states are a mixture of $l=0$ and $l=2$ transfers. However, this earlier study with unpolarized projectiles could not distinguish between $d_{3/2}$ and $d_{5/2}$ transfer.

The data on the transitions to the ground states and 2_1^+ states in the residual $^{190,192}Os$ nuclei are consistent with one-step, predominantly $d_{3/2}$ single particle transfer. In ^{190}Os the 2_2^+ and 4_1^+ states are nearly degenerate and, therefore, the analyzing power to the 2_2^+ state cannot be extracted from the present work. However, the analyzing power to the 2_2^+ state in ^{192}Os is near zero at one angle and definitely positive at 40°. Therefore, this transition cannot be dominated by one step $d_{3/2}$ transfer, but rather

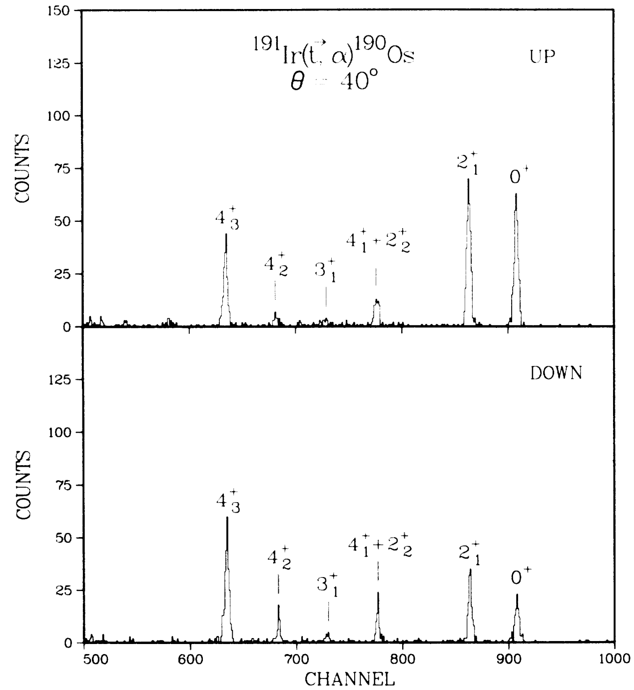

FIG. 1. Portion of the spectrum of the $^{191}\mathrm{Ir}(\vec{t},\alpha)^{190}\mathrm{Os}$ reaction at 40° with spin "up" and "down." States are labeled by their known (Ref. 16) J^{π} values.

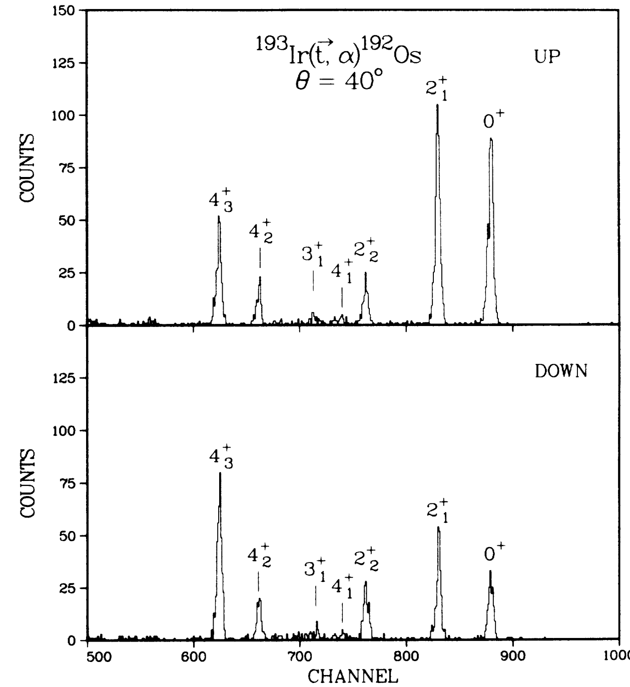

FIG. 2. Portion of the spectrum of the $^{193}\mathrm{Ir}(\vec{t},\alpha)^{192}\mathrm{Os}$ reaction at 40° with spin "up" and "down." States are labeled by their known (Ref. 17) J^{π} values.

TABLE I. Results from $^{191,193}\mathrm{Ir}(\vec{t},\alpha)^{190,192}\mathrm{Os}$ measurements.

E_x[a] (keV)	J_i^{π}[a]	$\sigma(\mu b/sr)$[b] 35°	40°	A_y[b] 35°	40°	A_yDW[c] (40° c.m.)
			^{191}Ir target			
0.0	0_1^+	37.(2)	42.(2)	−0.71(5)	−0.72(7)	−0.77
186.7	2_1^+	46.(2)	48.(3)	−0.61(5)	−0.58(9)	−0.76
547.9	2_2^+					−0.76
		13.2(2)	14.(2)	−0.41(10)	−0.02(14)	
558.0	4_1^+					+0.50
756.0	3_1^+	2.9(14)	3.5(14)			+0.49
955.4	4_2^+	6.5(16)	7.3(18)	+0.45(21)	+0.47(23)	+0.49
1163.2	4_3^+	45.(2)	45.(2)	+0.51(7)	+0.27(7)	+0.48
			^{193}Ir target			
0.0	0_1^+	41.(2)	42.(3)	−0.76(5)	−0.76(7)	−0.74
205.8	2_1^+	49.(2)	48.(2)	−0.69(5)	−0.56(6)	−0.73
489.1	2_2^+	13.7(16)	15.8(19)	+0.01(10)	+0.22(12)	−0.72
580.3	4_1^+	2.5(16)	2.7(14)			+0.47
690.4	3_1^+	4.6(15)	3.8(13)			+0.47
909.6	4_2^+	10.8(16)	11.6(17)	+0.40(13)	+0.10(14)	+0.46
1069.5	4_3^+	36.(2)	39.(2)	+0.35(7)	+0.33(8)	+0.46

[a]Known (Refs. 16 and 17) excitation energies and J^{π} values for low-lying states in ^{190}Os and ^{192}Os, respectively.

[b]Cross sections and analyzing powers at 35° and 40° measured in the present work. Errors in parentheses are on the last digits and are statistical.

[c]Analyzing powers at 40° (c.m.) calculated with DWUCK4 (Ref. 18) assuming single step $2d_{3/2}$ transfer (0^+ and 2^+ states) and $2d_{5/2}$ transfer (3^+ and 4^+ states).

must include some $d_{5/2}$ transfer strength and/or reflect a more complicated, higher order reaction mechanism via inelastic scattering coupled with single particle transfer.

The fact that the 2_2^+ state in ^{192}Os is not populated by a single-step $d_{3/2}$ particle transfer indicates that this transition is outside the framework of the U(6/4) supersymmetry description, which assumes that the only single particle orbital that can be populated is $j=\frac{3}{2}$. The present observation casts doubt on the suitability of the other odd$\rightarrow$even mass transfer reaction studies as tests of the supersymmetry model because these measurements were not done with a polarized projectile which is more sensitive to the single particle total angular momentum transferred and the reaction mechanism. Although it would be an important test of the supersymmetries if more of these odd$\rightarrow$even mass transfer reaction studies could be done with polarized projectiles, it is unlikely that many such experiments will be performed given the paucity of polarized beam facilities.

In spite of all of these caveats about the ability to extract meaningful spectroscopic factors from the Ir$\rightarrow$Os transfer reactions, there is evidence that the supersymmetry description as presently formulated may be inadequate to describe these nuclei because of its inability to reproduce any of the odd$\rightarrow$even mass transfer reactions. The argument that $d_{5/2}$ transfer may be misinterpreted as $d_{3/2}$ transfer may be appropriate for the U(6/4) supersymmetry tests. However, the failure of the supersymmetry to account for transfer to 2_2^+ states starting with ^{195}Pt targets[7] cannot be as readily dismissed, since in this case a multi-j U(6/12) supersymmetry ($j=\frac{1}{2},\frac{3}{2},\frac{5}{2}$) is predicted to occur.[19] In discussing transfer, therefore, only the distinction between allowed $f_{5/2}$ and excluded $f_{7/2}$ transfer would be observed. In the odd Ir and Au nuclei[3,20] the $\frac{5}{2}^+$ states at $\sim$500 keV receive about 20% of the total $d_{5/2}$ strength. In contrast, little low-lying $f_{7/2}$ strength is observed[4] in the odd-Pt nuclei, and, therefore, probably relatively little $f_{7/2}$ strength would be expected to be low-lying in the even Pt nuclei. The need for coupled-channels effects to be incorporated into the reaction mechanism is also not so obvious because one step distorted wave (DW) calculations can reproduce the shapes of angular distributions to 2^+ states, while coupled-channels effects often distort angular distributions significantly,[21] typically making them more forward peaked than one step calculations would predict.

The ground and 2_1^+ states in ^{190,192}Os are populated with negative analyzing powers, supporting the supersymmetry assumption that a $d_{3/2}$ proton is important in the low-lying spectra in this region.

The other strongly populated levels are the 4_3^+ states at 1163 and 1069 keV in ^{190,192}Os, respectively. It was previously proposed that these were hexadecapole vibrations because of their strong population in an earlier unpolarized (t,α) reaction study.[22] This interpretation was later supported by (α,α') measurements.[23] In terms of the strong-coupled Nilsson model the dominant component in these states, which would be populated in a $(\vec{t},\alpha)$ reaction, is the $K^\pi=4^+$, $\{\frac{5}{2}^+[402]+\frac{3}{2}^+[402]\}$ two-quasiproton configuration. In this model the $\frac{3}{2}^+[402]$ proton exists as the ^{191,193}Ir target ground state, and a $\frac{5}{2}^+[402]$ proton must be picked up in the reaction. The wave function of the $\frac{5}{2}^+[402]$ orbital is mainly $d_{5/2}$, so the transfers would be dominated by $l=2$, $j=\frac{5}{2}$ transitions. The positive analyzing powers observed for these states in the present work indicate the transitions have $J=l+\frac{1}{2}$, and thus support the interpretation described above. (Although it is not expected that the Nilsson model presents a good description of the Os-Ir Nuclei, in an asymmetric rotor model, which is more applicable, the dominant components of low-lying orbitals will be the Nilsson orbitals discussed above and, hence, the arguments will continue to be valid.)

However, the observed deexcitation pattern of the proposed members of these $K^\pi=4^+$ quasibands is not similar to that of a deformed $K^\pi=4^+$ band, in that the experimental branching ratios differ markedly from the Alaga rules. Rather, for all members of the 4^+ bands in ^{190,192}Os, the observed branching ratios are well reproduced by perturbed O(6) calculations,[11] in that they follow the $\Delta\tau=\pm1$ $E2$ selection rule of this symmetry. This agreement between experiment and theory then suggests that these states contain a multiphononlike component of an s-d boson O(6) character. However, the $E4$ excitations cannot be explained with only s and d bosons. A unified picture of these $K^\pi=4^+$ bands, which incorporates their $E4$ character and $E2$ deexcitations, has been obtained recently by Baker and co-workers[24] who have considered the 4_3^+ excitation to be a g boson, which would have as its geometrical analog a hexadecapole vibration. With their calculation, in which mixing is included between the g boson and usual s-d boson states, the observed $E2$ branching ratios and $E4$ matrix elements in ^{192}Os are reproduced by a g-boson admixture of $\approx$77% in the 4_3^+ state.

The ^{191,193}Ir$(\vec{t},\alpha)^{190,192}$Os reactions have been studied at two angles, and the analyzing powers to 2_2^+ states indicate that these states are not populated by single step $d_{3/2}$ transfer. The present results suggest that caution is necessary in using Ir$\rightarrow$Os single particle transfer reactions as a test of the U(6/4) supersymmetry because of the ambiguities in the reaction mechanism populating the 2_2^+ states. However, the universal failure of the supersymmetry models to reproduce any of the odd-A to even-A transfer reactions in the Os-Hg region may indicate the need for further developments within the model to explain these measurements.

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