Test of Supersymmetry in the ^{193}Ir → ^{194}Pt Proton-Stripping Reactions

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A breakdown of the selection rules of the supersymmetry model is observed for the population of the $0_2{}^+$ and $2_2{}^+$ levels of ^{194}Pt in the ^{193}Ir→ ^{194}Pt proton-stripping reactions performed with use of the Orsay and McMaster University tandem accelerators. The existence of other violations in the neighboring nuclei leads one to believe that the limitations of the supersymmetry scheme itself are being seen, at least for particle-transfer reactions.

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It was recently suggested[1] that dynamical supersymmetries might be present in the spectra of complex nuclei. A dynamical supersymmetry is defined as a situation in which the states of both boson (even-A) and fermion (odd-A) systems can be simultaneously classified by a complete set of group-theoretical labels, their energies being given, as a function of these labels, by a common expression.

In the interacting-boson model IBA1, the collective degrees of freedom of even nuclei are described as interacting S and D bosons around an inert core. Three natural dynamical symmetries, corresponding to situations where certain terms of the Hamiltonian dominate the others, have emerged: SU(3), close to the axial rotor; SU(5), close to the anharmonic vibrator; and O(6), somewhat similar to the γ-unstable rotor. It has been found[2] that the platinum nuclei (particularly ^{196}Pt) are well described by the O(6) limit. Recently the model was extended to the odd-A nuclei by adding a fermion to the bosons (IBFA). Iachello[1] was able, in a particular case, to find a group accommodating both the bosons and the fermion: the group Spin(6) including an O(6) representation describing the bosons and a spinor representation describing a fermion with $j=\frac{3}{2}$. The model based on this group representation has been applied successfully[1] to the level schemes in the ideal case of the even Pt and odd Ir nuclei.

The levels of these nuclei can be labeled by the spin and parity values and by two principal quantum numbers σ and τ ($\sigma=\sigma_1$ and $\tau=\tau_1$ of Ref. 1). (Examples of such labels are given in Figs. 1–3 of Ref. 1.) The model gives[3] selection rules for electromagnetic transitions and single-particle-transfer reactions. In odd-A gold nuclei the electromagnetic transitions expected to be forbidden in the model were found[4] to be at least strongly inhibited. For particle-transfer reactions, considering the simplest transfer operator, the transitions are allowed only if they obey the selection rules[3]

$$\Delta\sigma=\pm\tfrac{1}{2},\quad \Delta\tau=\pm\tfrac{1}{2}.$$

These predictions have been tested[5] through the study of the proton-pickup reactions Pt → Ir. The selection rules (and more precise intensity rules[3] as well) for the population of the $J^\pi=\frac{3}{2}^+$ levels are obeyed in the ^{194}Pt → ^{193}Ir case, but the agreement is getting worse when going towards the heavier Ir isotopes. The different pattern observed[6] for the population of the same $J^\pi=\frac{3}{2}^+$ levels in the reaction ^{192}Os(^{3}He, d)^{193}Ir is also very nicely explained by the above selection rules. In both cases the transitions classified as forbidden are very weakly populated, i.e., less than 8% of the allowed ground-state population. It should, however, be remarked that even in the ^{194}Pt → ^{193}Ir reactions, where the relative populations of the $J^\pi=\frac{3}{2}^+$ levels are correctly predicted by the model, the population of the lowest $J^\pi=\frac{1}{2}^+$ level, forbidden in the supersymmetry scheme, seems to be appreciable.

Another test of the selection rules is provided by the proton-stripping reactions ^{193}Ir → ^{194}Pt. In this case the selection rules forbid the population of the excited 0^+ levels and only the $0_{\text{g.s.}}{}^+$ of ^{194}Pt should be populated. For the 2^+ levels, the population of the $2_1{}^+$ is allowed but the population of the $2_2{}^+$ is forbidden.

The reaction $^{193}\text{Ir}(^3\text{He}, d)^{194}\text{Pt}$ was performed at 36 MeV with use of the Orsay MP tandem accelerator and the split-pole spectrometer, on an enriched (98.7%) ^{193}Ir target of thickness ≈ 50 μg/cm^2. The counting rate was very low and spectra were taken at only three angles ($\theta_{\text{lab}} = 10°$, 17°, and 38°). Two spectra were also taken with the McMaster University tandem and split-pole spectrometer: one at 25.5 MeV and $\theta_{\text{lab}} = 50°$ for the reaction $^{193}\text{Ir}(^3\text{He}, d)^{194}\text{Pt}$; the other at 27 MeV and $\theta_{\text{lab}} = 60°$ for the reaction $^{193}\text{Ir}(\alpha, t)^{194}\text{Pt}$. The cross sections extracted from these different spectra were in all cases corrected for the nonnegligible kinematic variation with excitation energy with use of distorted-wave Born-approximation (DWBA) calculations[7] with appropriate standard optical potentials. These corrected experimental relative cross sections are compared in Table I. The good agreement between data at different energies and with different reactions is an indication that two-step processes do not play a dominant role. This conclusion is strengthened for some levels that are appreciably populated in the present experiments (such as the $0_2{}^+$ and $2_2{}^+$ levels) by the fact that they are negligibly populated in inelastic-scattering experiments.[8,9]

The average experimental cross sections are compared, in Table I, with the predictions of the supersymmetry selection rules. It is clear that there is a strong disagreement, the important population of the $0_2{}^+$ and $2_2{}^+$ levels being particularly striking. Indeed, the two 2^+ levels are about equally populated, although one transition is allowed and the other is forbidden.

Another example of violation $[\sigma(2_2{}^+)/\sigma(0_{\text{g.s.}}{}^+) \approx 40\%]$, similar to but not as striking as the one observed in the present work, may be found in previously published data[10] for the reaction $^{193}\text{Ir}(t, \alpha)^{192}\text{Os}$, and we have pointed out the appreciable population of the first $J^\pi = \frac{1}{2}^+$ level in the reaction $^{194}\text{Pt}(t, \alpha)^{193}\text{Ir}$. A similar very appreciable population of the low-lying $J^\pi = \frac{1}{2}^+$ level has been observed[11] in the reaction $^{194}\text{Pt}(^3\text{He}, d)^{195}\text{Au}$. With the number of significant violations which we can now list [i.e., several transitions in different reactions, each supposedly forbidden but found to have (30–60)% of the allowed ground-state strength], we are seeing the limitations of the supersymmetry description of the ^{192}Os, ^{193}Ir, ^{194}Pt, ^{195}Au multiplet, at least as far as predictions for single-nucleon transfer are concerned.

In view of the success of the supersymmetry model in explaining the energy levels and the $E2$ matrix elements in the Ir–Pt nuclei,[9] it has been suggested[3] that at least a part of the difficulty may lie in the simplified form assumed for the one nucleon transfer operator when deriving the selection rules. The use of a correct operator[12] might lead to a relaxation of the selection rules and transitions with $\Delta\tau = \pm\frac{3}{2}$ could become allowed,[3] explaining the population of the $2_2{}^+$ level. This point has to be further explored theoretically. However, such an argument cannot explain the population of the $0_2{}^+$ level (pure $d_{3/2}$ transfer with $\Delta\tau = \frac{5}{2}$). The important population of this level in the present experiments clearly indicates that the breaking of the supersymmetry scheme is of

TABLE I. Comparison of experimental cross sections with the supersymmetry model selection rules.

		Experimental cross sections[a]				
E_{exc} (keV)	J^π	(^{3}He,d) 36 MeV	(^{3}He,d) 25.5 MeV	(α,t) 27 MeV	Average results	Selection rules
0	$0_{\text{g.s.}}{}^+$	100[b]	100[b]	100[b]	100[b]	Allowed
328	$2_1{}^+$	65	59	56	60 ± 5	Allowed
623	$2_2{}^+$	75	64	70	70 ± 5	Forbidden
1270	$0_2{}^+$	45	28	33	35 ± 10	Forbidden
1479	$0_3{}^+$	15[c]			15 ± 5	Forbidden
1547	$0_4{}^+$	$\lesssim 7$	$\lesssim 7$		$\lesssim 7$	Forbidden

[a] See Ref. 7.

[b] Normalized.

[c] A rough estimate of the strength of the 0^+ component has been obtained by a mixed-l analysis of the "angular distribution" corresponding to the well-known close doublet 0^+(1479 keV), 7^-(1485 keV).

the order of 35% in transfer reactions.

The present paper shows evidence in transfer reactions for an important breaking of the supersymmetry selection rules proposed by Iachello,[1,3] with at least a 35% breaking of the supersymmetry scheme itself. In view of the interest of the problem, it should stimulate other experimental and theoretical works to understand further the limits of validity of the supersymmetry model.

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Relationship between the Bohr Collective Hamiltonian and the Interacting-Boson Model

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The version of the interacting-boson model (IBM) which treats neutrons and protons symmetrically can be converted into a Bohr Hamiltonian description in three steps: (1) Mapping the IBM pairing bosons onto a quadrupole particle-hole–type boson under a generalized Holstein-Primakoff transformation; (2) introduction of pseudocanonical coordinates and momenta; (3) expansion in powers of the pseudomomenta, valid for large particle numbers. The limiting symmetries of the IBM emerge directly from a study of the potential-energy surface.

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In view of the impressive achievments of the interacting-boson model (IBM) in describing nuclear collective motion at low excitation energies,[1] there has been mounting interest in understanding as precisely as possible its connection with the established phenomenology, the Bohr collec-