PROCEEDINGS OF THE 49th SUMMER SCHOOL OF CORSICA, ON ELEMENTARY MODES OF EXCITATION IN NUCLEI

Realistic Shell Model Calculations.

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Introduction.

The title « Realistic Shell Model Calculations » for this sequence of lectures is in many ways a misnomer. An important educational aspect of the lectures will be to emphasize some of the many distinctions between actual nuclei and the corresponding constructs of a model. Nonetheless, the title « realistic » is ultimately appropriate for the line of research to be described in that the theoretical work is very strongly oriented towards the explanation of the reality which is revealed in experimental observations. The goal of this work is to bring as many as possible of the aspects and results of experimental nuclear spectroscopy into one coherent, unified theoretical scheme. This scheme, which shall be referred to hereafter as the « *j*-*j* coupling shell model » or just « shell model », can be considered as the direct logical extension, guided and implemented by such people as RACAH, ELLIOT, TALMI and FRENCH, of the shell model of Mayer and Jensen [1]. The « extension » is to explicitly consider the mixing of the various zeroth-order shell model configurations under the influence of a residual particle-particle interaction.

The term « shell model » is, quite appropriately, associated with a great variety of theoretical formalisms which have as their starting point the same Mayer-Jensen picture. The specific type of calculation to be discussed here can be delimited by noting various sets of initials which are *not* correct modifiers of « shell model » as it will be used in the following: these include BCS, HF, RPA, BHF, HFB, SU_3 and N (for Nilsson). In the first part of these lectures we shall outline the general physical and formal features of *j*-*j* coupling shell model calculations and specify the details of the particular calculations (for $A = 18 \div 38$ nuclei) which shall be discussed in depth. Relationships between this type of nuclear theory and alternate formulations and between the various elements of actual nuclear phenomena and their analogues in theoretical models will receive only brief comment. This first part is closed with

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VI-A-f

The Observation of Hole States in (p, t) Reactions at High Excitation†

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A peak about 2 MeV wide is observed at 8 to 9 MeV of excitation in a number of even even tin isotopes and at lower excitation in ^{104}Cd and ^{102}Pd in studies of the (p, t) reaction at 42 and 45 MeV. The excitation energy of the peak centroid and the peak width are observed to increase with increasing neutron number. It is suggested that the peak arises from two neutron pickup from the lower lying filled gpf shell between magic numbers 28 and 50. This explanation is reasonably consistent with the observed excitation energies. In addition, distorted wave born approximation (DWBA) calculations of the angular distributions for two neutron pickup from this shell agree in shape with the data. About 40% to 50% of the predicted total strength is observed experimentally.

The spreading of simple states into an underlying background of more complex states remains one of the important questions in nuclear physics.[1] One method of studying this problem is by pickup reactions particularly at high excitation energy where the level density is substantial. Neutron hole states with spin-parity $9/2^+$, $1/2^-$ and $3/2^-$ and with significant spectroscopic factors have been observed at about 5 MeV of excitation in the odd tin isotopes in single neutron pick-up reactions.[2–4] The present (p, t) experiment, was motivated by a search for high-lying pairing resonances in the tin isotopes.[5] The original estimate of the excitation energy of the 0^+ pairing resonance was at $70/A^{1/3}$ MeV, i. e., about 14.1 MeV for ^{122}Sn. A more realistic calculation[6] which involves diagonalization of the pairing force in RPA suggests that substantial 0^+ strength will be observed around 8 MeV of excitation for this mass region.

The initial measurements on the ^{122}Sn (p, t) reaction were carried out at a proton bombarding energy of 45 MeV and the tritons were detected in a standard counter telescope consisting of three Si detectors. This arrangement permitted the study of ^{120}Sn up to an excitation energy of about 17 MeV. No structure was observed near 14 MeV but a substantial "bump" was observed around 8.5 MeV excitation.

In order to study this phenomenon in more detail, the ^{122}Sn (p, t) reaction was repeated at a proton bombarding energy of 42 MeV using a 50 cm long resistive wire proportional counter backed by a plastic scintillator in the focal plane of the Enge spectrograph. This arrangement gave very clear identification of the tritons but was restricted to measuring a range of triton energies from about 32.5 MeV to 21.5 MeV. Again an enhancement of the cross section was observed near 8.5 MeV in ^{120}Sn, quite consistent with the observations at 45 MeV using the silicon counter telescope. This excluded the possibility that the effect had an instrumental origin.

The (p, t) experiment was continued at 42 MeV on the even tin isotopes, ^{124}Sn, ^{120}Sn, ^{118}Sn and ^{116}Sn using the Enge spectrograph. The energy resolution was dominated by the target thicknesses which ranged from 0.5 to 5 mg/cm^2. The spectra obtained from these measurements at a laboratory angle of 16° are plotted in Fig. 1, using the same absolute energy scale. A peak, about 2 MeV wide at an excitation energy between 8 and 9 MeV is

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Presented by G. M. Crawley.

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X-I-e Extraction of Deformation Parameters from Inelastic Proton Scattering*

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This experiment reports the measurement of the inelastic scattering of 35 MeV protons from the nuclei ^{154}Sm, ^{176}Yb, ^{232}Th and ^{238}U. Angular distributions were extracted for the ground state rotational band. The data were compared with coupled channel calculations using a deformed optical potential and values of the deformation parameters β_2 and β_4 were extracted. These values, together with the multipole potential moments are compared to the results of Coulomb excitation, electron scattering, and inelastic α-scattering measurements. In general, the potential moments extracted from the present (p, p′) measurements agree better with those from the Coulomb excitation and electron scattering measurements than with the moments from (α, α'). However, the deformation parameters from (p, p′), corrected for the projectile size, agree much better with values obtained from high energy α-scattering than with deformation parameters extracted from Coulomb excitation and electron scattering experiments.

The determination of nuclear shapes is one of the most fundamental problems in the study of nuclear deformations. The lowest order (quadrupole) moments of static deformed nuclei have been fairly well established by various techniques, most notably through electromagnetic measurements. Interest has now to a large extent shifted to the determination of the hexadecapole and other higher-order nuclear deformations, particularly since calculations have shown¹⁾ that nuclear binding energies are quite sensitive to the presence of hexadecapole deformations. Thus, for example, the magnitude of the hexadecapole deformations in the actinide nuclei could have considerable bearing on whether longlived superheavy nuclei exist.¹⁾

After inelastic scattering cross sections were shown²,³⁾ to be sensitive to higher-order nuclear deformations, inelastic scattering experiments have become the principal method of measuring nuclear shapes. There are two categories of such measurements. One set of measurements is sensitive only to the charge (proton) distribution of nuclei and includes Coulomb excitation by hadronic projectiles and inelastic electron scattering. The other group of measurements consists of high-energy scattering by hadronic projectiles which are sensitive to both the neutron and proton distributions.

One question of considerable interest which might be investigated by a comparison of these two groups of measurements concerns whether the deformations of the neutron and proton distributions in a nucleus are the same. However, such a comparison is by no means straightforward. Because the Coulomb interaction is well understood, Coulomb excitation and electron scattering both yield quantities (transition moments and charge form factors, respectively) which can in principle be directly related to the charge distribution of the nucleus. Such is not the case for scattering which involves the nuclear force because the exact form of the projectile-nucleus effective interaction is unknown. Perhaps the most fundamental method currently available for relating the nuclear matter distribution with scattering cross sections involves the use of a folding model prescription for the projectile-nucleus interaction.⁴⁾ Even this technique involves considerable uncertainties because of such questions as the correct form of the nucleon-nucleon effective interaction, how to include exchange effects, and how to treat the imaginary part of the

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R(4) Group Theoretical Description of Deformed Nuclear States*

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The rotation group *R*(4) is peculiarly useful for describing deformed systems because all its operations can be given in explicit analytical form (for higher groups this is not true). Thus, we can write definite expressions for spherical harmonics, vector-coupling coefficients, etc., and can apply tensor-operator techniques directly to such systems. An elegant treatment of diatomic molecules using *R*(4) has been published¹⁾, and much of the formalism can be taken over to a description of deformed nuclear states. We describe the rigid rotor, its application to even-even nuclei (including rotation-vibration coupling), and particle-rotation coupling in odd-mass nuclei (including Coriolis-induced distortions). We also describe the simpler electromagnetic transitions between deformed nuclear states, up to and including *E*2's. Up to now the *R*(4) methods of analysis merely corroborate what can be determined by more conventional analyses, but their power promises to cut through and simplify much of the messy mathematics of these conventional methods.

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*Work supported in part by the U.S. National Science Foundation.

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SUB-KeV MASS MEASUREMENTS AND SUPER-ALLOWED BETA DECAY*

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Precise measurements of end-point energies in 0^+ to 0^+ super-allowed beta decay are very important for the determination of the vector coupling constant of nuclear beta decay, as well as in testing the various calculations of charge dependent corrections to the beta decay matrix elements. In particular, the importance of the ^{14}O-^{14}N decay energy has recently been emphasized by Wilkinson [1]. The present measurement of the mass of ^{14}O was carried out in an attempt to clarify the disagreement between two recent measurements [2,3] and previous determinations of this mass [4,5,6]. The results of these five previous measurements and the present preliminary result are compared in table 1. We also give in the table the preliminary result of our measurement of the mass of ^{10}C together with the only previously reported sub-keV measurement [7] of this nucleus.

The present measurements utilized the MSU cyclotron-magnetic spectrograph system and the momentum-matching calibration procedure described previously [8]. The ^{14}O and ^{10}C masses were determined by comparing the triton momenta from the $^{16}O(p,t)$ and $^{12}C(p,t)$ reactions with deuteron and proton momenta from the $^{15}N(p,d)^{14}N$ and various (p,p') reactions. The recently reported precise value of the ^{15}N-^{14}N mass difference [9] served as the primary energy standard for this work. The decay energies are derived from the Q-values using the stable isotope mass differences (^{16}O-^{14}N and ^{12}C-^{10}B) from ref. 9 and 10.

The discrepancies seen in table 1 are disquieting since the present result implies an $f^R t$-value for the ^{14}O-^{14}N case of 3098±5 as compared with a value of 3079 ± 6 sec. based on the Münich Q-value measurement [2]. Because of the significance of these discrepancies the present data are being reexamined for systematic errors as well as to reassess the reliability of the presently quoted uncertainties. The goal is to reconcile the differences between the three completely independent methods of the Münich [2], Auckland [3,7], and the present work so as to permit increased confidence in the ft - values.

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† On leave from University of Auckland, Auckland, New Zealand.
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1 D.H. Wilkinson, Phys. Lett. 67B(77)13
2 H. Vonach et al, Nucl.Phys. A278(77)189
3 R.E. White and H. Naylor, Nucl.Phys. A276 (77)333
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9 L.G. Smith and A.H. Wapstra, Phys. Rev. C11 (75)1392
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Table 1. Summary of sub-keV measurements of the ^{14}O and ^{10}C decay energies.

	$Q_\beta(0^+\text{-}0^+)^a$	Difference	Method	Calibration	Reference
^{14}O	1809.34±0.7	-1.03±0.9	$(^3He,n)$ thres.	electrostatic anal.	6
	1810.24±0.5	-0.13±0.8	$(^3He,n)$ thres.	$^7Li(p,n)$ thres.	5
	1810.54±0.5	+0.17±0.8	$(^3He,n)$ thres.	time of flight (rf)	4
	1808.78±0.4	-1.59±0.7	(p,n) thres.	alpha source	3
	1807.88±0.8	-2.49±1.0	$(^3He,t)$ Q-value	time of flight (rf)	2
	1810.37±0.6	----	(p,t) Q-value	^{15}N-^{14}N mass diff.	present
^{10}C	1910.11±0.6	+3.28±0.9	(p,n) thres	alpha source	7
	1906.83±0.7	----	(p,t) Q-value	^{15}N-^{14}N mass diff.	present

[a] All values in keV. All values calculated using masses from references 9 and 10.

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Gamow-Teller Beta Decay in sd-shell Nuclei*

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We have used the wave functions of Chung and Wildenthal[1] to calculate the matrix elements for allowed Gamow-Teller Beta decay for essentially all observed transitions in the $17\leq A\leq 39$ region. These wave functions uniformly span the full d5/2-s1/2-d3/2 model space and the results are therefore unaffected by truncations which might restrict the d5/2 - d3/2 occupancy ratios. The comparison of the calculated transition rates with the observed values alternately offers a test of the validity of the model and/or the specific Hamiltonians employed and a means of determining the need, if any, for a renormalization of the free-nucleon parameterization of the Gamow-Teller operator in this model space.

The matrix elements, $\langle\sigma\tau\rangle$exp, were extracted from the experimental data in a manner similar to that used by Wilkinson[2] assuming $|g_A/g_V|=1.251(9)$. 54 matrix elements between A=17 and 39 were used to determine the average reduction $\langle\sigma\tau\rangle$exp/$\langle\sigma\tau\rangle$th(s.p.) as well as the fitted one-body matrix elements, $\langle jj'\rangle$fitted/$\langle jj'\rangle$s.p. where $\langle jj'\rangle = \langle j||\sigma\tau||j'\rangle$. The results for various mass regions are given in Table 1. The average reduction factors are consistent with the quenching obtained by Wilkinson.[2] However, due to cancellation effects each one-body matrix element requires much more quenching.

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1) W. Chung and B.H. Wildenthal, to be published

2) D.H. Wilkinson, Nucl. Phys. A209, 470(1973).

Table 1

	$\langle jj'\rangle$fitted/$\langle jj'\rangle$s.p.				
	2j2j'=55	11	53	33	average reduction
A =17$^{1)}$	0.878(7)				
39$^{1)}$				0.675(8)	
17-39$^{2)}$	0.844(12)	0.813(20)	0.694(14)	0.744(28)	0.888
17-26$^{2)}$	0.846(13)	0.815(33)	0.694(21)		0.902
25-33$^{2)}$	0.811(13)	0.812(13)	0.697(16)	0.845(37)	0.922
33-39$^{2)}$		0.786(41)	0.703(24)	0.738(24)	0.820

$^{1)}$Experimental error only
$^{2)}$Fit error only

(p,t) REACTIONS ON ^{41}K, ^{42}Ca AND ^{43}Ca AND CORE EXCITED STATES*

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It has been noted that direct reactions involving transfer of two identical nucleons provide special insights into the core excitation components of wave functions of excited states, because of the strongly correlated nature of the transferred pair. In order to study weak (or simple) coupling relationships between states of even-even nuclei and adjoining odd-A nuclei, we have studied the (p,t) reaction on fifteen pairs of even-even and odd-A nuclei ranging from ^{23}Na to ^{115}In.

A beam of 40 MeV protons from the MSU sector-focused cyclotron was used and the tritons were momentum analyzed in an Enge split-pole spectrograph and detected in a position sensitive single-wire proportional counter backed by a scintillation detector. In the present experiment an energy resolution, FWHM ≈ 20 keV was realized. The spectroscopic results obtained are presented in the adjoining table. As indicated therein, a large number of states $|J_f\rangle$ in the odd-A nuclei ^{39}K and ^{41}Ca show essentially pure single L-transfer, instead of a mixture of allowed angular momenta ranging from $J_i + J_f$ to $|J_i - J_f|$. We interpret this as an indication of the parentage of these states in the states with $J^{\pi} = L^{(-1)^L}$ of the adjoining even-even 'core' nucleus. Based on detailed analysis of angular distribution shapes, absolute cross sections and excitation energies, we have been able to identify the multiplets in ^{39}K and ^{41}Ca associated with the 0^+, 2^+, 3^- and 5^- states of ^{40}Ca. In several cases the identification of these correspondences and the expectation of a $(2J_f + 1)$ proportionality according to rules for weak coupling have enabled us to make suggested J assignments (indicated in parantheses) for states in ^{39}K and ^{41}Ca.

^{41}Ca				^{39}K				^{40}Ca		
E(keV)	L	2Jπ	Strength	E(keV)	L	2Jπ	Strength	E(keV)	Jπ	Strength
0	0	7-	S	0	0	3+	S	0	0+	S
1940	2	3-	M	2523	2	1+	M	3354	0+	S
2010	3+5	3+	S	2811	3	7-	M	3738	3-	S
2463	2+4	3-	M	3020	3	3-	M	3900	2+	S
2589	2	5-	M	3595	3	9-	S	4495	5-	S
* 2604	1+3	5+	M	3882	3	(5)-	S	5208	0+	
2670	3	1+	M	* 3941	0+(2)	3+	S	5247	2+	S
* 2882	3	7+	M	4126	3	7-	S	5628	2+	M
* 2960	0	7-	S	4513	5	(13)-	M	5903	1-	
* 3040	2	5-	M	4521				6026		M
* 3201	3	9+	M	* 4678	0+(2)	3+	M	6286	3-	
3372	3	11+	S	4738	3	5-	M	6508	4+	M
3399	3	1+	M	* 4935	0	3+	M	6582	3-	M
* 3526	3	3+	M	* 5173	5	(9)-	S	6752	(2-)	
3614	3	+	M	5266	2	(5)+	S	6909	2+	M
* 3674	2	-	M	* 5319	0	3+	S	6951	1-	M
3733	3	+	S	5360	5	11-	M	* 7113	(3-)	M
3831	5	(15)+	S	* 5501	0+(2)	3+	M	* 7301	0+	
3915	3+5	(13)+	M	* 5597	2	(1)+	M	* 7430	(2+)	
* 3996	2	-	S	* 5713	0	3+	S	7673	2+	M
4094	3	5+	M	* 5788	3+5	-	M	* 7558	(2+)	M
* 4281	2	7-	M	5875	3	-		* 7620	0+	M
* 4360	2	11-	S	* 5938	3	-		7653	(4-)	T=1
* 4530	5	+	M	* 6050	(0+2)	(3+)	M	* 7695	0+	M
* 4733	3	+	M	* 6181	3	(3)-	M	7757		
4971	3+(5)	9+	M	* 6243	2	(3)+	M	7805		
* 5061	2	9-	M	* 6322	0	3+	M	7871	2+	M
* 5121	2	-	M	* 6450	2	(7)+	S	* 7926	(3-)	M
* 5220	5	(17)+	M	* 6531	5	7-, T=3/2	M	7978		
* 3355	0	7-	S	* 7040	3	(9)-	M	* 8025	0+	
5818	3+5	3+, T=$\frac{3}{2}$	S	* 7122	3	(7)-	M	* 8087	4+	M
* 5953	3	+	M	* 7269	(0+2)	(3)+	M	8113		
* 6050	3	+	M	* 7337	3	(5)-	M	8197	(2+)	
6516			M					8279		
6822	3	1+, T=$\frac{3}{2}$	M					8337		
* 7024	3	+	M					* 8375	4+	M
7138	0	7-, T=$\frac{3}{2}$	M					* 8433	0+	M
								* 8483	0+	
								8548	5- T=1	S
								8579	5-	
								* 8666	4+	
								* 8752	3-	
								8853		
								* 8905	(6+)	
								* 8939	0+	
								8983		
								9033		
								9157		
								9250		
								* 9263	(2+)	
								9304	0+	
								* 9386	2+	
								* 9405	0+ T=1	S
								9569		
								9592		
								9661		M

S $\geq$ 5% of g.s.

5% $\geq$ M $\geq$ 1%

blank $\leq$ 1%

Spin and/or parity assignments for states marked with asterisks are new.

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1. K. K. Seth, et al., Phys. Rev. Lett. <u>30</u>, (1973) 132; also Phys. Lett. <u>49B</u> (1974) 157, Phys. Lett. <u>59B</u> (1975) 333, Phys. Rev. Lett. <u>35</u>, (1975) 609.

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(p,t) REACTIONS ON ^{44}Ca AND ^{45}Sc AND CORE-EXCITED STATES

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It has been noted[1] that direct reaction unvolving transfer of two identical nucleons provide special insights into the core-excitation components of nuclear wave functions, because of the strongly correlated nature of the transferred nucleon pair. In order to reveal core-excited components in states of odd-A nuclei and to study weak (or simple) coupling relationships between these states and the states of the adjoining even-even nuclei, we have investigated the (p,t) reaction on fifteen pairs of even-even and odd-A nuclei ranging from ^{23}Na to ^{115}In. Here we report on the reactions ^{44}Ca(p,t)^{42}Ca and ^{45}Sc(p,t)^{43}Sc.

A beam of 40 MeV protons from the MSU sector-focused cyclotron was used and tritons were momentum analyzed in an Enge split-pole spectrograph and detected in a position sensitive single-wire proportional counter backed by a scintillation counter. In the present experiment an energy resolution, FWHM = 20 keV was realized. Data was taken from 6° to 50°. The spectroscopic results obtained are presented in the adjoining table. In ^{42}Ca as well as ^{43}Sc a large number of spin and/or parity assignments are new (indicated by asterisks). In ^{43}Sc all states with identifiable L = 0 components have the unique $7/2^-$ assignment; for all other states only the parity, π is determined uniquely and spin assignments (inidated in parantheses) can only be made by indirect arguments.

As indicated in the Table, a large number of states $|J_f\rangle$ in ^{43}Sc show an essentially pure, single L-transfer instead of a mixture of the allowed angular momenta which range from $J_i + J_f$ to $|J_i - J_f|$. We interpret this as an indication of the parentage of these states in the states with $J[\pi] = L[(-1)^L]$ in the adjoining even-even 'core' nucleus. Based on detailed analysis of angular distribution shapes, absolute cross sections and excitation energies, we have been able to identify the multiplets in ^{43}Sc associated with the 0^+ and 2^+ states in ^{42}Ca and to make suggested spin assignments on the basis of the weak-coupling picutre.

^{42}Ca E(keV)	$J\pi$	Strength	^{43}Sc E(keV)	ℓ	$2J\pi$	Strength
0	0^+	S	0	0	7^-	S
1522	2^+	S	467	2	3^-	
1836	0^+	M	841	2	5^-	M
2422	2^+	M	1176	2	3^-	
2749	4^+	S	1336		7^+	
3186	6^+	S	* 1407	0	7^-	M
3250	4^+	M	1810	2	3^-	
3297	0^+		1828	2	11^-	S
3392	2^+	S	* 1889	2	9^-	S
3445	3^-	S	1939	5	9^+	
3653	2^+	M	* 2110	(5+3)	+	
*3996	5^-		* 2246	2	$(3-7)^-$	
4045	3^-		2291	4	5^-	M
4099	5^-	S	* 2337	2	$(5-9)^-$	M
*4352	5^-		* 2460	2	$(5-9)^-$	M
4430	3^-		2549	(5,6)		
*4504	(4^+)		* 2633	2	$(7)^-$	M
4684	3^-	S	* 2670	2	$(\leq 7)^-$	
4757	2^+	S	* 2760	4	-	M
			* 2793	2	-	M
4863	(2^+)		* 2838	5	+	M
4896	5^-	S	* 2859	3	+	
4968	3^-	M	2984	4	$(15)^-$	S
5014	4^+		3123	6	$(19)^-$	M
5213	2^+		* 3205	(4)	-	
*5332	0^+	M	* 3257	4	-	
5354			* 3290	2	$(3,5)^-$	M
*5379	(6^+)		3328	2	$(5,7)^-$	M
5464	(4^+)		3373	2	-	M
5500	(3^-)		* 3448	5	+	M
*5530	2^+		* 3480	3	+	M
*5591	(4^+)	M	* 3509	0	7^-	
5664	3^-		* 3676	3	+	M
*5713	2^+	M	* 3700	6	-	M
5775			* 3771	5	+	M
5809		M	* 3807	5	+	M
			* 3848	5	+	M
			* 3907	3	+	
			* 3949	3	+	M
			* 4015	5	+	
			* 4049	4	-	M
			* 4138	5	+	
			* 4169	4	-	M
			* 4211	3	+	M
			4239	0	7^-	S
			⋮		T=3/2	⋮
			5236	5	+	M

Note:

Spin and/or parity assignments for states marked with asterisks are new.

S $\geq$ 5% of g.s.

5% $\geq$ M $\geq$ 1%

blank $\leq$ 1%

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* Research supported in part by the U. S. Energy Research and Development Administration and the National Science Foundation.

[1] K. K. Seth, et al., Phys. Rev. Lett. 30, (1973) 132; also Phys. Lett. 49B (1974) 157, Phys. Lett. 59B (1975) 333, Phys. Rev. Lett. 35, (1975) 609.

PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON NUCLEAR STRUCTURE
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Shell Model Description of the ^{50}Ti(p,t) and ^{51}V(p,t) Reactions

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High resolution ^{50}Ti(p,t)^{48}Ti and ^{51}V(p,t)^{48}V experiments with E_p=40 MeV have been carried out. The differential cross sections integrated from 6-55° for the lowest few known levels of each spin are given in Table I. These are compared with the cross sections predicted assuming pure $f_{7/2}$ configurations for both initial and final states. The theoretical cross sections were calculated with the zero-range DWBA code DWUCK using L-dependent enhancement factors ϵD_o^2 chosen to give best overall agreement for the ^{48}Ti data. (ϵD_o^2 $\approx$155-, 64-, 25- and 14- x 10^4 MeV^2 - fm^3 for L=0, 2, 4 and 6, respectively). The ^{49}V cross sections represent a sum over all possible L transfers.

Theory (I) was obtained using wavefunctions obtained with the empirical $f_{7/2}^2$ ^{42}Sc interaction[1] by assuming for T=1 V_{pp}=V_{pn}=V_{nn}. In contrast theory (II) was obtained using the empirical two-particle spectra V_{pp}=^{50}Ti, V_{pn}=^{48}Sc and V_{nn}=^{46}Ca. For ^{48}Ti (II) is in better agreement with experiment than (I). The ^{48}Ti wavefunctions with (II) have considerable signature[2] mixing. Overall both (I) and (II) are in very good agreement with the ^{49}V data. The fact that an excited 7/2$^-$ state with predominantly L=2 character is observed, is reproduced by the $f_{7/2}$ model. However, the theoretical $f_{7/2}$ ^{49}V - ^{48}Ti overlaps indicate that weak coupling wavefunctions[3] are not very good approximations for ^{49}V.

Table I

J_f	exp Energy keV	exp σ µb	th(I) σ µb	th(II) σ µb
^{48}Ti(π= +)				
0	0	42.2	42.2	42.2
2	985	21.1	18.1	21.1
2	2416	9.4	12.5	9.4
4	2295	4.47	5.51	5.93
4	3238	9.58	8.54	8.06
6	3333	6.26	4.13	6.44
6	3511	2.90	5.00	2.75
^{49}V(π= -)				
3/2	153	1.16	1.17	1.08
3/2	1662	1.19	1.64	1.82
5/2	91	1.28	1.17	1.30
5/2	1516	2.45	2.26	2.23
7/2	0	36.6 1)	37.0 1)	35.5 1)
7/2	2183	5.0 2)	4.5 2)	4.4 2)
9/2	1154	5.5	3.0	3.0
9/2	2350	1.4	3.2	3.5
11/2	1020	6.08	5.90	6.61
13/2	2861	2.02	1.48	1.42
15/2	2263	1.17	1.34	1.56

1) Mostly L=0
2) Mostly L=2

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1) Kutschera et al., to be published in Revista del Nuovo Cimento.
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PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON NUCLEAR STRUCTURE
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(p,t) REACTIONS ON ^{50}Ti AND ^{51}V AND CORE-EXCITED STATES*

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It has been noted[1] that direct reactions involving transfer of two identical nucleons provide special insights into the core-excitation components of nuclear wave functions, because of the strongly correlated nature of the transferred nucleon pair. In order to reveal core-excited components in states of odd-A nuclei and to study weak (or simple) coupling relationships between these states and the states of the adjoining even-even nuclei, we have investigated the (p,t) reaction on fifteen pairs of even-even and odd-A nuclei ranging from ^{23}Na to ^{115}In. Here we report on the reactions ^{50}Ti(p,t)^{48}Ti and ^{51}V(p,t)^{49}V.

A beam of 40 MeV protons from the MSU sector-focused cyclotron was used and tritons were momentum analyzed in an Enge split-pole spectrograph and detected in a position sensitive single-wire proportional counter backed by a scintillation counter. In the present experiment an energy resolution, FWHM = 17 keV was realized. Data was taken from 6° to 50°. The spectroscopic results obtained are presented in the adjoinging table. In ^{48}Ti as well as ^{49}V a large number of spin and/or parity assignments are new (indicated by asterisks). In ^{49}V all states with identifiable L = 0 components have the unique 7/2$^-$ assignment; for other states only the parity, π is determined uniquely and spin assignments (indicated in parantheses) can only be made by indirect arguments.

As indicated in the Table, a large number of states $|J_f\rangle$ in ^{49}V show an essentially pure, single L-transfer instead of a mixture of the allowed angular momenta which range from $J_i + J_f$ to $|J_i - J_f|$. We interpret this as an indication of the parentage of these states in the states with $J[\pi] = L[(-1)^L]$ in the adjoining even-even 'core' nucleus. Based on detailed analysis of angular distribution shapes, absolute cross sections and excitation energies, we have been able to identity the multiplets in ^{49}V associated with the 0^+ and 2^+ states in ^{48}Ti and to make suggested spin assignments on the basis of the weak-coupling picture.

^{48}Ti E(keV)	Jπ	Strength	^{49}V E(keV)	L	2Jπ	Strength
0	0+	S	0	0	7-	S
985	2+	S	91	2	5-	M
2295	4+	S	153	2	3-	M
*2416	2+	S	1020	2	11-	S
2999	0+	S	1154	2	9-	S
*3238	4+	S	1516	2	5-	M
3333	6+	S	1662	2	3-	M
3363	2+	S	2183	0+2	7-	S
3511	6+	M	2235	2	5-	M
3621	2+		2263	4	15-	M
3745			2306	2	3-	M
3852		M	2350	2	9-	M
4044		M	2404	0	7-	M
*4077	4+	M	*2666	2	11-	M
4393	4+	M	2727			M
*4535	0+		2786	2	(9,11)-	M
4589	3-	S	*2811	2	(5,7)-	M
*4725	4+	M	2861	4	13-	M
4794	3-	S	3020	2	(3,7)-	M
*4912	5-	S	*3136	0+2	7-	M
			*3241	0	7-	M
			3305	4	-	M
			*3332	(0)	(7-)	M
			*3347	2	(9)-	M
			3398	2	(5)-	M
			*3479	0	7-	M
			*3534	(0)+2	(7)-	M
			*3609	0+2	7-	M
			*3624	4	-	M
			*3649	4	-	M
			*3685	0+2	7-	M
			*3728	2	(5)-	M
			3757	6	(7)-	M
			*3795	4	-	M
			*3825	2	(3)-	M
			*3886	(0)+2	(7)-	M
			3910	4+(6)	(3)-	M
			*3975	2	(11)-	M
			*4048	3+5	+	M
			*4098	3+(5)	+	M
			*4165	0+2	7-	M
			*4209	(0)+2	(7)-	M
			*4277			M
			*4305	3+5	+	M

Notes:

S = ≥ 10% of g.s.

M = 10% to 1%
blank = <1%

The spin and/or parity assignments for states marked with asterisks are new.

In an accompanying paper the predictions of $(f_{7/2})^n$ model calculation are also examined in relation to our experimental results.

*Research supported in part by the U.S.Energy Research and Development Administration and the National Science Foundation

1. K.K.Seth, et al., Phys. Rev. Lett. 30, (1973) 132; also Phys. Lett. 49B (1974) 157, Phys. Lett. 59B (1975) 333, Phys. Rev. Lett. 35, (1975) 609.

2. B. A. Brown, H. Nann and K. K. Seth, contribution submitted to this conference.

PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON NUCLEAR STRUCTURE
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(p,t) REACTIONS ON ^{88}Sr AND ^{87}Sr AND CORE-EXCITED STATES*

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It has been noted[1] that direct reactions involving transfer of two identical nucleons provide special insights into the core-excitation components of nuclear wave functions, because of the strongly correlated nature of the transferred nucleon pair. In order to reveal core-excited components in states of odd-A nuclei and to study weak (or simple) coupling relationships between these states and the states of the adjoining even-even nuclei, we have investigated the (p,t) reaction on fifteen pairs of even-even and odd-A nuclei ranging from ^{23}Na to ^{115}In. Here we report on thereactions ^{88}Sr(p,t)^{86}Sr and ^{87}Sr(p,t)^{85}Sr.

A beam of 40 MeV protons from the MSU sector-focused cyclotron was used and tritons were momentum analyzed in an Enge split-pole spectrograph and detected in a position sensitive single-wire proportional counter backed by a scintillation counter. In the present experiment an energy resolution, FWHM $\simeq$ 15 keV was realized. Data was taken from 6° to 50°. The spectroscopic results obtained are presented in the adjoining table. In ^{86}Sr as well as ^{85}Sr a large number of spin and/or parity assignments are new (indicated by asterisks). In ^{85}Sr all states with identifiable L = 0 components have the unique 9/2$^+$ assignment; for all other states only the parity, π is determined uniquely and spin assignments (indicated in parantheses) can only be made by indirect arguments.

As indicated in the Table, a large number of states $|J_f\rangle$ in ^{49}V show an essentially pure, single L-transfer instead of a mixture of the allowed angular momenta which range from $J_i + J_f$ to $|J_i - J_f|$. We interpret this as an indication of the parentage of these states in the states with $J[\pi] = L[(-1)^L]$ in the adjoining even-even 'core' nucleus. Based on detailed analysis of angular distribution shapes, absolute cross sections and excitation energies, we have been able to identify the multiplets in ^{85}Sr associated with the 0^+ and 2^+ states in ^{86}Sr and to make suggested spin assignments on the basis of the weak-coupling picture.

^{86}Sr			^{85}Sr			
E(keV)	Jπ	Strength	E(keV)	L	2Jπ	Strength
0	0+	S	0	0	9+	S
1077	2+	S	236	2	7+	S
1855	2+	M	741	5	3-	M
2102	0+	S	766	2	5+	S
*2202	0+	S	*791	6	+	M
2230	4+	S	942	5	5-	M
*2480	3-	S	1114	2	13+	S
2641	2+	M	1153	(3)	-	M
2668	5-	S	*1220	2	(11)+	S
2785	2+	S	*1262	0+2	9+	S
2856	6+	S	1357	2	(5)+	M
*2957	8+	S	*1409	6	+	M
2997	3-	S	*1487	4+(2)	+	M
*3057	5-	M	1558	4+(2)	+	M
3106	(2+)		*1589	(3)	(-)	M
3192	(2+)	M	*1626	0	9+	S
*3328	4+	M	*1657	(4+2)	+	M
*3360	0+	M	*1688 1712	3+5	-	S
*3377	2+	M				
*3443	2+	S	*1853	(4+2)	+	M
*3499	(7-)	S	1925	2	+	M
*3660	4+	M	*1984	2	+	M
*3708	2+	S	*2049	0+(2)	9+	S
*3790	(3-)	M	*2101	3+5	-	S
*3835	5-	M	*2123	(3)	(-)	M
*3900	(3-)	M	*2163	(3)	(-)	S
*3948	4+	M	*2201	(3)	(-)	M
*3967	5-	M	*2238	2	(7)+	M
*4148	2+	M	*2297	5	-	S
4207		M	2325	2	(5)+	M
*4287	(2+)	M	2366	5	-	S
*4328	4+	S	*2406	2	(13)+	S
*4409	(2+)		*2458	2	(11)+	S
*4486	0+	M	*2474	(3)	(-)	S
*4558	4+	S	2528	3+5	-	M
			2560	3+5	-	M
			2602	(4)	(+)	M
			*2626	2+(0)	(9)+	M

S = ≥ 10% of g.s.
M = 1% to 10%
blank < 1%

Note:
The spin and/or parity assignments for states marked with asterisks are new.

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* Research supported in part by the U. S. Energy Research and Development Administration and the National Science Foundation.

[1] K.K.Seth, et al., Phys. Rev. Lett 30, (1973) 132; also Phys. Lett. 49B (1974) 157, Phys. Lett. 59B (1975) 333, Phys. Rev. Lett. 35, (1975) 609.

Excitation of Giant Resonances in ^{90}Zr by Inelastic ^{6}Li Scattering*

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Inelastic scattering of 75 MeV ^{6}Li-particles has been used to study the giant resonance region of ^{90}Zr. The spectra, taken at angles between 11° and 25° with a magnetic spectrograph, were all quite similar and show three regions of enhanced cross section. As can be seen in Fig. 1 below, the giant quadrupole resonance is quite strongly excited at an excitation energy of 13.8 ± 0.3 MeV in good agreement with previous work1). In addition a broad enhancement at 22.3 ± 0.6 MeV is present in all the spectra which were obtained. There also appears to be a region of very strong cross section at 6-9 MeV.

The main advantage of ^{6}Li ions over the previously used lighter projectiles is the relatively lower yield to the non-giant resonant part of the continuum. The 22.3MeV enhancement for example may be present in α-scattering spectra, but it is rendered unobservable by the large α yield from evaporation, compound nuclear and other multiparticle breakup reactions. The main disadvantage of ^{6}Li ions, at least at 75 MeV energy, is that the angular distributions have relatively poor discrimination between L-values. Above 10 MeV excitation, the shapes of angular distributions are smooth and featureless with hardly any L-dependence.

The data were analyzed with DWBA2) using optical parameters from elastic scattering at the same energy3). The strengths given under various L-value assumptions were obtained with a method very similar to that of the α-scattering work1). These are listed in the table below and indicate that the 22.3 MeV enhancement must come from $L \geq 3$ since it is much too strong for any lower L. The L=3 or giant octupole resonance is expected4) to be split into two components, one at around 7 MeV and the other near 20 MeV, and this may account for a large fraction of the observed enhancements.

Table I--Giant resonance parameters obtained from (^{6}Li,^{6}Li').

Excitation Energy	Γ(MeV)	% EWSR			
		E0	E2	E3	E4
13.8 ± 0.3 MeV	3.8 ± 0.4	533%	58%	20%	9%
22.3 ± 0.6 MeV	4.0 ± 0.7	9200%	660%	223%	52%

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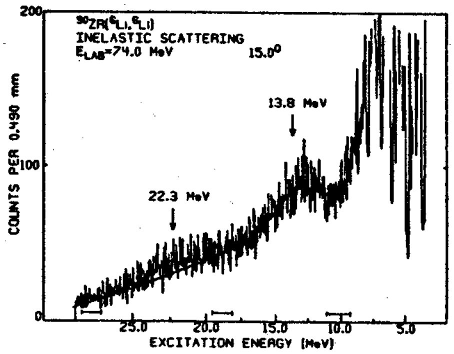

PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON NUCLEAR STRUCTURE
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Observation of the Giant Gamow-Teller Resonance in the (^{3}He,t) Reaction at 130 MeV

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Giant resonances in charge exchange (T=1) reactions have been seen as analogs of the ground states of target nuclei (IAS) since the work of Anderson and Wong. In these transitions, giant Fermi transitions, S=0. A giant Gamow-Teller (G-T) (S=T=1) transition producing a broad peak near the sharp Fermi peak has been observed at MSU in the (p,n) reaction on ^{90}Zr with 45-MeV protons.[1] The resonance is built upon ($\pi g_{7/2}, \nu g_{9/2}^{-1}$) particle-hole excitations. As the resonance (in ^{90}Nb) has T=4, whereas ^{90}Zr has T=5, it may also be considered the anti-analog of the giant M1 resonance in ^{90}Zr. As the T=5 analog state should be at higher excitation and more weakly excited, it was not seen in the (p,n) experiment.

Using a Si-Ge, ΔE-E telescope and targets of ^{90}Zr, ^{120}Sn, and ^{208}Pb, we have studied charge-exchange transitions via (^{3}He,t) with the 130-MeV ^{3}He beam at the Jülich cyclotron. Data were taken from about 10° to 35° at 1° intervals.

The figure shows representative triton spectra obtained with the ^{90}Zr target. The Fermi (or IAS) peak is the most prominent feature of the spectra. There is also a broad, structured peak near the Fermi peak. The location and width of the broad peak agree with what was seen in the neutron spectra and interpreted as the giant G-T transition. In ^{120}Sn spectra, however, there is only the slightest hint of a broad peak under the IAS, and in the ^{208}Pb spectra the only peak is the IAS.

An important feature of these spectra is that they run to very high excitation energies and that they exhibit almost no structure beyond the IAS or G-T. In the ^{90}Zr spectra, however, there is a slight bump around 19 MeV excitation energy. Conceivably, it is the $T_>$ part of the G-T transition, that is, the T=5 component, whose existence is a necessary part of the giant G-T interpretation of the (p,n) and (^{3}He,t) data. The isospin splitting would the be ∼ 10 MeV, somewhat above earlier estimates.[2] Its energy above the Fermi IAS, ∼ 13.5 MeV, is ∼ 3.3 MeV below the energy for the analog of the T=1, E1 resonance in ^{90}Zr.[3]

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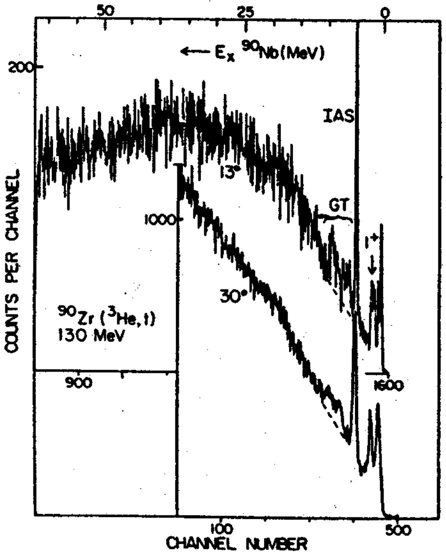

PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON NUCLEAR STRUCTURE
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The Observation of Hole States in (p,t) Reactions at High Excitation*

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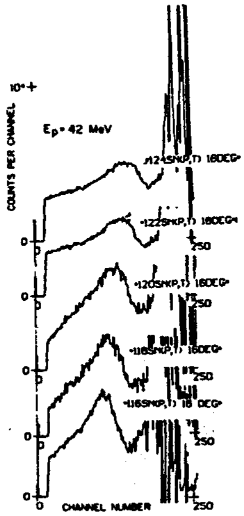
In order to search for the high lying pairing resonances which were suggested by Broglia and Bes[1] to explain renormalization effects in two particle transfer processes a series of tin isotopes was studied using the proton beam from the Michigan State University Isochronous Cyclotron. An initial search was made on ^{122}Sn at 45 MeV with a standard counter telescope. The experiment was repeated at 42 MeV on the isotopes ^{116}Sn, ^{118}Sn, ^{120}Sn and ^{124}Sn, using the Enge split pole spectrometer.

No structure was observed near the excitation energy for the lowest pairing resonance modes predicted by Broglia and Bes to be at $70/A^{1/3}$ MeV (14.1 MeV for ^{122}Sn). However broad peaks were observed at excitation energies between 8 and 9 MeV for all the tin isotopes investigated. The angular distribution for this peak in ^{120}Sn was similar to that for the first 2^+ state. The spectra obtained from these measurements at a laboratory angle of 16° are shown in Figure 1 in which the spectra are plotted on the same absolute energy scale. Excitation energies as well as Q-values for these peaks are shown in Table 1. In addition, the reactions ^{106}Cd(p,t), ^{104}Pd(p,t), ^{144}Sm(p,t) and ^{208}Pb(p,t) were measured. A broad peak at about the same Q-value was also observed in the first three of these nuclei, but for the ^{106}Cd and ^{104}Pd cases the excitation energy was low enough to permit fine structure to appear in the peak. However, no strong effects like those discussed above were observed for the ^{208}Pb target.



One possible interpretation of these results is that the peak arises from pickup from the next lowest major shell, particularly from the "hot orbits"[2] $p_{1/2}$ and $p_{3/2}$. Such deep hole states have been observed in single nucleon transfer reactions on the tin isotopes,[3] and therefore the present measurement will give information on the degree of pairing in these shells.

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* Work supported by the National Science Foundation.
+ On leave from Institute of Nuclear Research, Warsaw, Poland.

Table 1

Reaction	E_x(MeV)	Q Value for "Resonance" Peak
^{116}Sn(p,t)^{114}Sn	8.00 MeV	-16.64 MeV
^{118}Sn(p,t)^{116}Sn	8.42 MeV	-16.19 MeV
^{120}Sn(p,t)^{118}Sn	8.51 MeV	-15.62 MeV
^{122}Sn(p,t)^{120}Sn	8.65 MeV	-15.15 MeV
^{124}Sn(p,t)^{122}Sn	8.70 MeV	-14.66 MeV
^{104}Pd(p,t)^{102}Pd	5.90 MeV	-15.03 MeV

PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON NUCLEAR STRUCTURE
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HIGH RESOLUTION STUDY OF THE 'DEEP' HOLE STATES IN ^{115}Sn*

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In 1972 Sakai and collaborators[1] identified a broad bump in Sn(p,d) cross sections in the region of 5 to 7 MeV excitation as being related to 1g and 2p neutron hole states. van der Werf et al.[2] studied neutron pick-up in tin nuclei systematically by means of the (d,t) reaction with an energy resolution of about 150 keV and verified the general conjectures of Sakai et al. quantitatively. For example, for ^{115}Sn they reported observing a summed L = 4 strength, $\Sigma c^2S = 3.0$ i.e. 30% of that of $1g_{9/2}$ and a summed L = 1 strength, $\Sigma c^2S = 1.2$ i.e. 20% of that of $2p_{3/2,1/2}$. Berrier-Ronsin et al.[3] studied the same reaction with much better resolution, FWHM = 16-18 keV and verified the existence of the $\ell = 4$ enhancement but found its strength to be only half as much i.e. 15%. For $\ell = 1$ their conclusions were "less clear-cut" and they observed between 10% and 20% of the strength for the 2p-hole.

The interpretation of these bumps in terms of "deep" hole states acquires important significance only if a good fraction of the hole strength is identified. The question of spectroscopic strength is therefore all important. Experimentally, one of the major problems in the extraction of the strength lies in what one designates as the smooth background under the smooth bump. Obviously, the problem is less difficult if the structure in the bump can be resolved, i.e. we need the best resolution possible. Particle identification and identification of contaminant contributions is also of crucial importance. With these goals in mind we have studied the ^{116}Sn(p,d)^{115}Sn reaction at $E_p = 35$ MeV using the MSU cyclotron and the Enge-split pole spectrograph. Data was taken in the angular range 6° to 54° both with a position sensitive proportional counter and with photographic plates in the focal plane. For the counter data an energy resolution, FWHM = 15 keV was realized. For the photographic plate data an energy resolution, FWHM ≃ 5 keV was realized. Spectroscopic results from these high resolution studies will be presented.

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* Research supported in part by the U. S. Energy Research and Development Administration and the National Science Foundation

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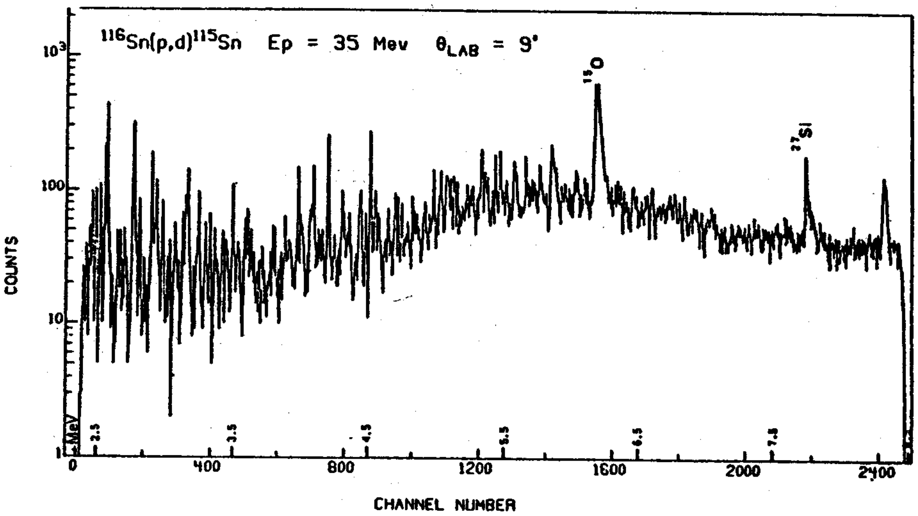

Study of High-Spin States in ^{146}Sm and ^{148}Sm*

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Recent theoretical calculations[1] have indicated that the light Sm nuclides may become oblate at low angular momenta, making possible the existence of yrast traps[2]. We have investigated the high-spin structures in ^{146}Sm and ^{148}Sm using the ^{146}Nd(α,4n) and ^{148}Nd(α,4n) reactions with E(α)=40-50 MeV.

Excitation function, γ angular distribution, γ-γ coincidence, and delayed γ experiments were carried out. No delayed γ rays in these nuclei were observed with half lives greater than a few nsec. The prompt decay schemes are shown below. Rotational structures are not observed; instead the yrast sequences seem to be dominated by multi-quasiparticle configurations. The spacings of many of the negative parity levels indicate possible weak coupling between the 3$^-$ state and the positive-parity levels. However, many more negative parity levels exist than can be accounted for in this way. Isotopic and Isotonic comparisons are being made.

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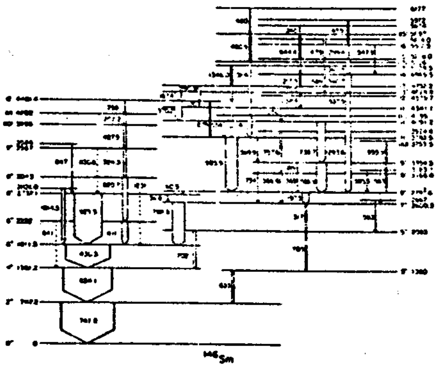

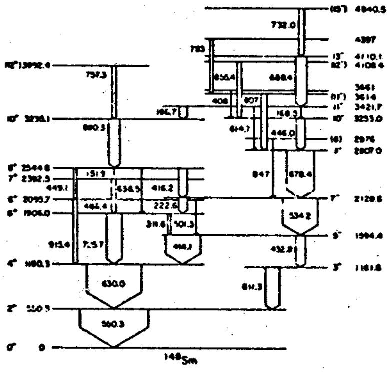

PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON NUCLEAR STRUCTURE
Tokyo, September 5-10, 1977

High-spin Level Structure in Odd-Mass Pb Nuclei*

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While high-spin levels in light even-A Pb nuclei have been studied in detail by several groups$^{1-3}$, little has been known up to now about high-spin levels in their odd-mass neighbors. We have investigated the high-spin level spectra of the five odd-A Pb nuclei in the mass range A = 195-203 by (α, 3nγ) and (^{3}He, xnγ) in-beam spectroscopy, and have observed strong yrast cascades terminating in known $13/2^+$ isomeric states in all five nuclei. The principal results of the investigations are summarized in the partial level schemes shown in Fig. 1, which also includes the even-A Pb level spectra$^{1-3}$.

The main features of the odd-A level spectra can be understood in terms of the coupling of known states of the even-A core nuclei with an additional $i_{13/2}$ neutron hole. The closely spaced $17/2^+$, $15/2^+$ and $19/2^+$, $21/2^+$ doublets are clearly marked as members of hole-core coupling multiplets associated with the 2_1^+ and 4_1^+ core states, and a hole-core coupling interpretation for the negative parity levels is also strongly indicated by the energy systematics. In addition, a comparison of the B(E1) and B(E2) values extracted from the many measured half-lives shows generally close agreement between the transition probabilities for corresponding transitions in adjacent odd-A and even-A nuclei. Overall, the weak coupling approach provides a rather satisfactory description of the systematic trends observed in the odd-A Pb spectra.

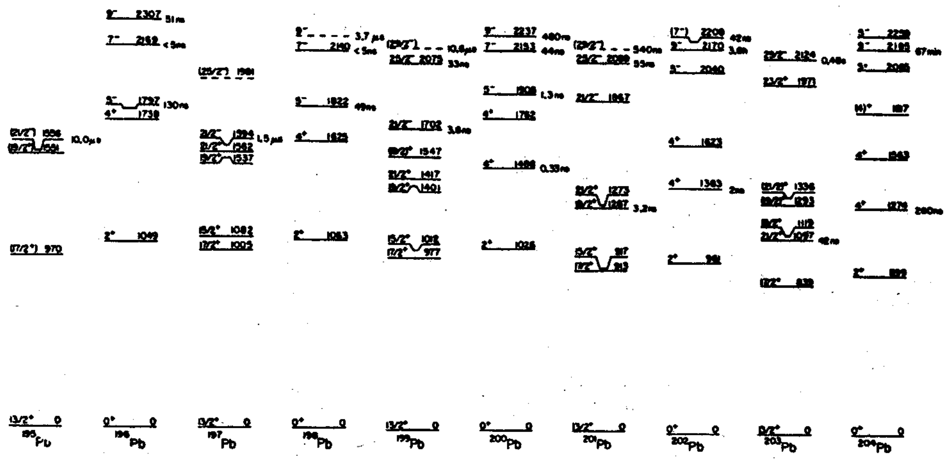

Fig. 1. High-spin levels in Pb nuclei. The $13/2^+$ states are known isomers.

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PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON NUCLEAR STRUCTURE
Tokyo, September 5-10, 1977

The Nuclear Coupling Constant for Analogs of Gamow-Teller Transitions in Charge Exchange Reactions - A Measurement at 25, 35, and 45 MeV Using the ^{7}Li(p,n)^{7}Be Reaction*

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A number of studies have taken advantage of the strong resemblance between the charge exchange operator $V_{\sigma\tau}(r)(\vec{\sigma}_i \cdot \vec{\sigma}_p)(\vec{\tau}_i \cdot \vec{\tau}_p)$ and the Gamow-Teller (GT) or M1 operators, to search for GT strength or analogs of M1 strength. To make these studies quantitative it is necessary to know the relevant nuclear coupling constant which is proportional to $V_{\sigma\tau}$. Unfortunately, nearly all empirical information about $V_{\sigma\tau}$ is obtained from studies of very light nuclei[1] and there are large reaction mechanism uncertainties.

We describe here measurements of cross sections for the ^{7}Li(p,n)^{7}Be reaction leading to the ground ($3/2^-$) and first excited (429 keV, $1/2^-$) states of ^{7}Be at 25, 35 and 45 MeV. Since $V_{\sigma\tau}$ dominates the cross section to the 429 keV state while the operator $V_\tau(\vec{\tau}_i \cdot \vec{\tau}_p)$ is important for the ground state, an analysis of the ratio of cross sections to these states should yield the ratio $V_{\sigma\tau}/V_\tau$, with much of the model dependence hopefully vanishing in the ratio. Since V_τ is relatively well known[2] in this energy region, one then obtains $V_{\sigma\tau}$.

Measurements were carried out with the MSU beam-swinger time of flight facility. Flight paths up to 30 m and overall time resolutions near 0.6 nsec permitted clean separation of the ground and first excited states at all energies. The cross sections at 25 MeV are shown in Fig. 1; the cross section ratio depends only weakly on angle.

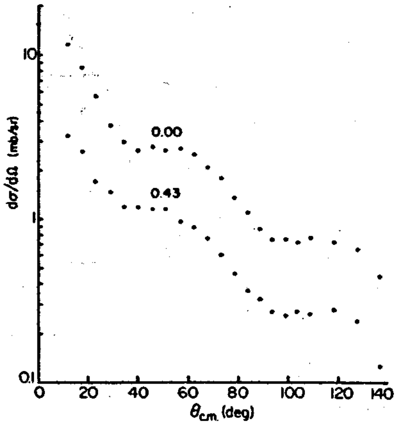
Initial analysis has been in terms of the model of Anderson, et al.[3], assuming only central forces (no tensor), plane waves and L=0 transfer. In this limit the necessary nuclear structure information can be obtained from β decay ft values and one obtains

$$\frac{V_\tau}{V_{\sigma\tau}} = \left[1.14 \left(\frac{\sigma_0}{\sigma_1}\right) - 1.34\right]^{1/2}$$

The results of the analysis are shown in Table I, and are in good agreement with previous results.[1] A more detailed analysis is in progress.

Table 1--Values of $V_{\sigma\tau}$ for 1 fm range Yukawa
$V_{\sigma\tau}(r) = V_{\sigma\tau} e^{-r}/r$.

E_p	σ_0(gs)	σ_1(429 keV)	V_τ(ref. 2)	$V_{\sigma\tau}$(MeV)
24.8	21.5 mb	7.60	17.0	12.4
35.0	14.6	5.95	15.3	12.7
45.0	11.2	5.14	14.6	13.7



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Nuclear Deformations from Proton Inelastic Scattering*

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The determination of the mass multipole moments of nuclei remains an outstanding problem in nuclear physics. Although the charge (proton) moments can be measured in a reasonably model-independent manner using such techniques as electron scattering and Coulomb excitation, determining the mass distribution moments (protons plus neutrons) requires for the most part hadronic probes. Unfortunately standard techniques for the extraction of moments, from hadronic scattering, such as the use of deformed optical potentials, have a number of strongly model-dependent features which have made comparison between measured mass and charge moments very uncertain[1,2]. The resolution of this dilemma will very likely require a more realistic analysis of the hadronic scattering experiments (e.g., using folding-model potentials) and these approaches are more readily adapted to nucleon scattering than to that of more complex projectiles.

Very little data exists for nucleon scattering on heavy deformed nuclei at energies high enough to be sensitive to the higher-order moments. Thus, we have begun a program to measure proton inelastic scattering on lanthanide and actinide nuclei at bombarding energies of 35 to 40 MeV. As is shown in fig. 1, the sensitivity to hexadecapole (β_4) deformations is comparable to that for 50-MeV α-particle scattering[3]. Fig. 2 shows that the resolution (7 keV) is sufficient to measure accurately angular distributions at forward angles for states up to the 10^+ of the ground band. We are presently analyzing the data in the traditional manner: varying the deformation parameters of the deformed optical potential to fit the angular distributions in a coupled-channel calculation. Preliminary values for the deformation parameters generally agree more closely with the 50 MeV α-scattering parameters, when the scaling procedure advocated by Hendrie[1] is applied, than with those determined by Coulomb excitation and electron scattering. We are presently determining the uncertainties in these deformation parameters, and plan eventually to try more realistic approaches to fitting the data.

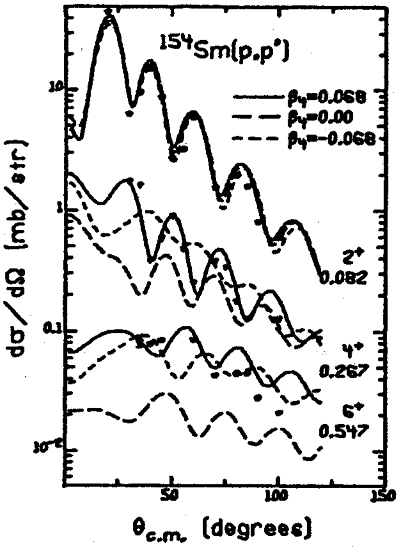
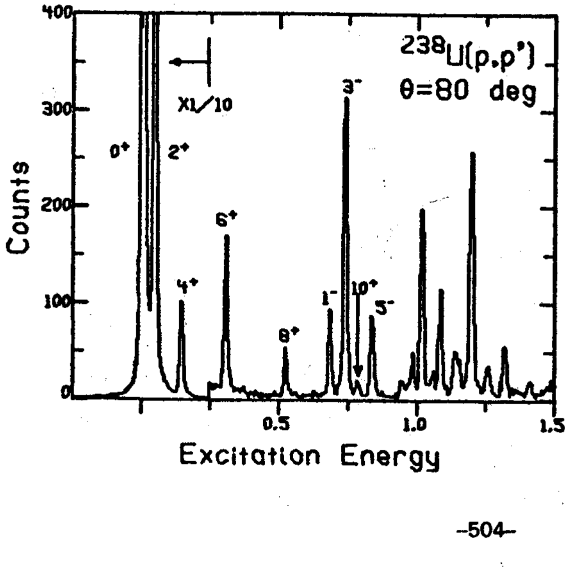


Figure 1

Figure 2



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PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON NUCLEAR STRUCTURE
Tokyo, September 5-10, 1977

The $^{54}Fe(p,d)^{53}Fe$ Reaction at 40 MeV and the DWBA Analysis

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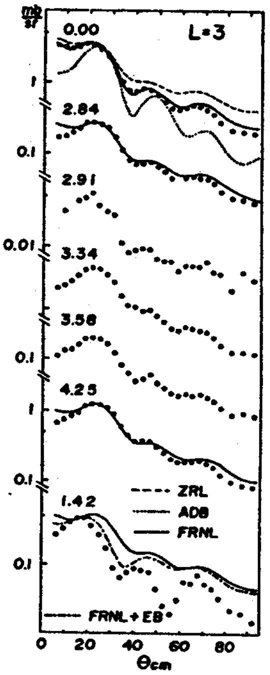
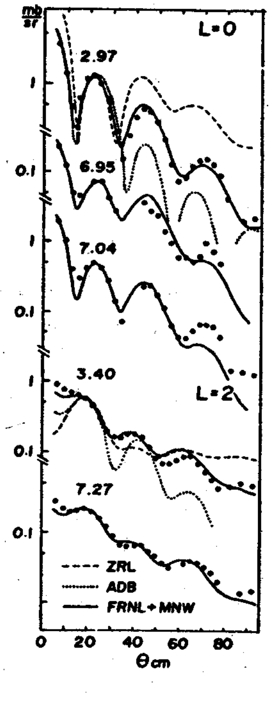
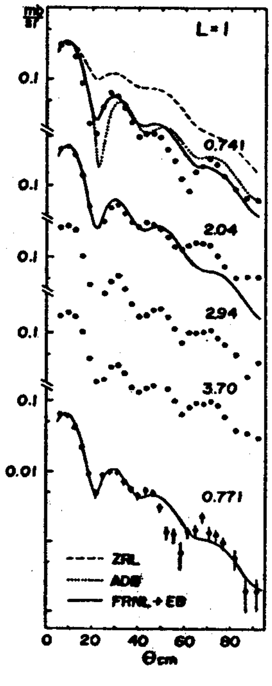
Angular distributions of deuterons from the $^{54}Fe(p,d)^{53}Fe$ reaction were measured with 40.16 MeV protons using a split-pole spectrograph and position sensitive proportional counter at the Michigan State University cyclotron. The measurement was done in the angular range from 6° to 90° with 15 keV resolution. Peaks hitherto unresolved in the (p,d) reaction were clearly resolved (0.741-0.771 MeV doublet, etc.).



Usual zero-range and local (ZRL) DWBA with optical-potential parameters of Newman[1)], Perey-Perey[2)] and of Hinterberg[3)] for deuterons gives poor fits for ℓ = 0, 1, 2 and 3 transfers. The adiabatic-model calculation[4)] (ADB) gives poorer results. Finite-range and non-local corrections (FRNL) improve fits for j = 7/2⁻ while fits for other transfers are still unsatisfactory. By use of the effective binding procedure (EB) fits were much improved for 3/2⁻, 1/2⁻(0.771) and for 5/2⁻(1.42) states.

For $d_{3/2}$ and $s_{1/2}$ hole states these procedures do not produce satisfactory results, nor does the well-radius search[5)] or radial-cutoff procedure. A largely modified Newman potential (MNW) gives shapes in agreement with the experiment. In conclusion in order to obtain reasonable agreement for angular distributions three different procedures are necessary for three cases: 1) 7/2⁻ transfers, 2) 3/2⁻, 1/2⁻ and 5/2⁻ and 3) ℓ = 0 and 2 transfers. This causes further difficulty in obtaining systematic spectroscopic factors for various j-transfers.





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* On leave from Tohoku Institute of Technology, Sendai 982, Japan.

PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON NUCLEAR STRUCTURE
Tokyo, September 5-10, 1977

Experimental and Theoretical Studies of ^{22}Na β Decay*

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The most interesting feature of ^{22}Na β decay is the anomalous experimental ε/β^+-decay branching ratio which differs from allowed theory by 8±1%. We have recently calculated the effects on the ε/β^+ ratio caused by the main second-order corrections to the simple allowed theory.$^{1)}$ These corrections introduce the familiar matrix elements$^{2)}$: b (weak magnetism), h (induced pseudoscalar), d (induced tensor), and c_2 (second-order Gamow-Teller). For moderate values of these matrix elements, an ε/β^+ skew ratio (experiment/theory), which we call V, can be calculated for ^{22}Na decay by the equation,

$$V = 1 - \left[18.0 \frac{c_2}{c_1 R^2} - 1.72 \frac{b}{Ac_1} + 0.71 \frac{d}{Ac_1} + 0.0017 \frac{h}{A^2 c_1} \right] \times 10^{-3} ,$$

where c_1 is the first order Gamow-Teller matrix element. The weak magnetism strength, b, can be inferred from CVC theory by measuring the $M1$ γ transition in ^{22}Na, the analog to the β decay. Using the $^{25}\mathrm{Mg}(p,\alpha\gamma)^{22}\mathrm{Na}$ reaction and α-γ coincidence measurements, we have set an upper limit of 0.25%/decay for an $M1$ transition from the $T=1$ analog state at 1952 keV in ^{22}Na to the $T=0$ ground state. This makes the b term a factor of three too small to explain the ε/β^+ ratio. The effects of c_2, h, or d must be established from spectral shape measurements and longitudinal polarization measurements, which are currently in progress. In either case, very large matrix elements are required, which cannot be explained by shell-model calculations in the impulse approximation.

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PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON NUCLEAR STRUCTURE
Tokyo, September 5-10, 1977

Upper Limit on Parity Mixing in the ^{93}Tc 17/2$^-$ Isomer

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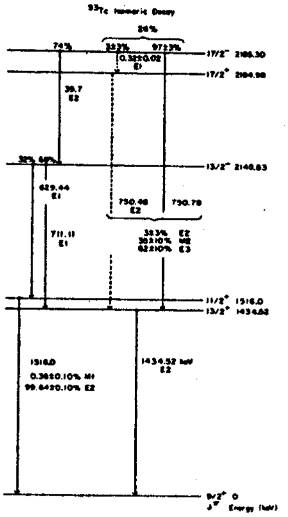
Recently in ^{93}Tc an isomeric 17/2$^-$ level was found to lie only about 0.44 keV above a 17/2$^+$ level at 2185 keV[1]. From the lifetimes of the two levels a limit of $|\langle 17/2^+ | H_{pv} | 17/2^- \rangle| \leq 0.34$ eV was derived for the matrix element of the parity-violating Hamiltonian.

We have investigated parity mixing effects in the 750.8 keV $17/2^- \rightarrow 13/2^+$ transition by measuring its angular distribution and linear polarization. The ^{93}Tc 17/2$^-$ isomer (τ=15 μsec) was populated by the ^{65}Cu(^{32}S,2p2n)^{93}Tc reaction at E(^{32}S)=120 MeV in a 1.8 mg/cm^2 thick target of ^{65}Cu. The evaporation residues were stopped in a thick Pb backing to preserve the nuclear alignment. The initial state alignment coefficients were obtained from the transitions of known multipolarity. The data for the 750.8 keV transition together with the previously determined[2] internal conversion coefficient were then used to determine relative E2, M2 and E3 strengths shown in the Fig. The results are 3±3%, 35±10% and 62±10% for the E2, M2 and E3 components, respectively. There is the possibility that the 3±3% E2 contribution could arise from an unresolved $17/2^- \rightarrow 17/2^+ \rightarrow 13/2^+$ cascade as shown in the Fig. A value of 3±3% for this E1 branch was obtained from measuring an angle dependent energy shift in the 750.8 keV γ ray due to the opposite signs of the a_2 coefficients for the two components. Thus from the present experiment an upper limit of $\Gamma(\mathrm{E2}\ 17/2^- \rightarrow 13/2^+)/\Gamma \leq 6\%$ is obtained. This together with a more recent determination[2] of the $17/2^+$-$17/2^-$ energy splitting of 0.32 keV yields $|\langle H_{pv} \rangle| \leq 0.06$ eV.



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PROCEEDINGS OF THE SYMPOSIUM ON SHELL-MODEL CALCULATIONS FOR
LIGHT AND MEDIUM WEIGHT NUCLEI
Tokyo, September 1977

Spectroscopic Amplitudes for Multi-nucleon Transfer in the $1f_{7/2}$ Shell

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I. Introduction

The $f_{7/2}$ shell model[1,2] has been found to provide a coherent description of many properties of a subset of energy levels in nuclei with 20 < N,Z < 28. In this work the success of this model in describing multi-nucleon transfer spectroscopic amplitudes is investigated. It is known that the $f_{7/2}$ model cannot account for the absolute magnitude for two-nucleon transfer because admixtures of nearby "hot" orbitals greatly enhance the cross section.[3] However, the $f_{7/2}$ model could be considered successful if at least relative spectroscopic factors can be predicted; this is similar to the effective charge concept for electromagnetic transitions.[4]

The wave functions are conveniently described in the proton-neutron formalism, for example

$$J_i = \sum_{J_{pi}J_{ni}} (a^{J_i}_{J_{pi}J_{ni}}) |(J_{pi},J_{ni})J_i>$$

where the J's stand for all indicies needed to distinguish the states. Then the most general spectroscopic amplitude for the transfer of p protons and n neutrons in the configuration $(J_p,J_n)J$ is,

INTERNATIONAL SYMPOSIUM ON NUCLEAR PHYSICS AT CYCLOTRON ENERGIES
Calcutta, INDIA, September 14-16, 1977

THE CREATION OF THE RARE LIGHT ELEMENTS - IMPLICATIONS FOR COSMOLOGY

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Abstract

THE CREATION OF THE RARE LIGHT ELEMENTS - IMPLICATIONS FOR COSMOLOGY. 1. Introduction; 2. Creation of the Rare Light Elements in the Galactic Cosmic Rays; 2.1. General Theory; 2.2. Techniques for Measuring Spallation Cross Sections; 2.3. Time of Flight Measurements; 2.4. Calculations of RLE Production in the Galactic Cosmic Rays - Comparison with Experimental Abundances; 3. Creation of the Rare Light Elements in a Big Bang; 3.1. Basic Cosmology; 3.2. Results of Standard Big Bang Calculations; 4. Cosmological Implications; 4.1. Constraints on the Mean Baryon Density ρ_b from the Deuterium Abundance; 4.2. Constraints on ρ_b from the Abundance of ^{7}Li; 5. Summary and Conclusions.

1. INTRODUCTION

It appears that most elements with mass A≥12 are synthesized in the centers of stars during their static burning stages and the supernovae that end their lives [1,2]. Most of the lighter elements, on the other hand, are too fragile to survive the temperatures and densities found in stellar centers and must therefore be created in a cooler and/or less dense environment. As a result, with the single exception of ^{4}He, these light elements are found in nature with abundances much less than those of their neighbors (see Fig. 1) and are collectively known as the rare light elements (RLE).

In recent years there has been great progress in understanding the processes which create the RLE. An unexpected byproduct of this understanding is the most convincing answer to date of the cosmological question: will the presently observed expansion of the Universe continue forever, or will the Universe eventually collapse again to a hot dense singularity? This talk will review theories of

INTERNATIONAL SYMPOSIUM ON NUCLEAR PHYSICS AT CYCLOTRON ENERGIES
Calcutta, INDIA, September 14-16, 1977

Inelastic Proton Scattering From Lanthanide and Actinide Nuclei*

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ABSTRACT

The inelastic scattering of 35 MeV proton is reported from the nuclei ^{154}Sm, ^{176}Yb, ^{232}Th and ^{238}U. Angular distributions were extracted for the ground state rotational band. The data were compared with coupled channel calculations using a deformed optical potential and values of the deformation parameters β_2 and β_4 were extracted. These values, together with the multipole potential moments are compared to the results of Coulomb excitation, electron scattering, and inelastic α-scattering measurements. The deformation parameters generally do not show good agreement for the different methods although the values obtained from the proton measurements are reasonably consistent with the values from high energy α-scattering. However, the potential moments from the present (p,p') measurements agree better with those from the Coulomb excitation and electron scattering measurements than with the moments from (α,α').

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PROCEEDINGS OF SYMPOSIUM ON GAMMA RAY SPECTROSCOPY IN ASTROPHYSICS
April, 1978

Cross Sections Relevant to Gamma Ray Astronomy†

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We have measured gamma-ray production cross sections relevant to gamma-ray line astronomy for protons and alpha particles incident on targets consisting of nuclei of high cosmic abundance: ^{12}C, ^{14}N, ^{16}O, ^{20}Ne, ^{24}Mg, ^{28}Si, and ^{56}Fe.

Solid or gaseous targets were bombarded by monoenergetic beams of protons and alpha particles, and gamma rays were detected by two Ge(Li) detectors. The proton energy for each target was varied from threshold to about 24 MeV (lab); for alphas the range was from threshold to about 27 MeV. For most transitions, it was possible to measure the total cross section by placing the detectors at 30.5° and 109.9°, where the fourth-order Legendre polynomial is zero. For the case of the ^{16}O ($E_\gamma = 6.13$ MeV, multipolarity E3) cross sections, we measured yields at four angles. Absolute cross sections were obtained by integrating the beam current and by measuring target thicknesses and detector efficiencies. The Ge(Li) detector resolution was a few keV (although the peak widths were greater, due to Doppler broadening).

An overview of the measured gamma-ray cross sections for incident protons is presented in Fig. 1, where the cross section and energy of the most prominent gamma-ray line for each target are displayed for several proton energies. Except for ^{16}O, these lines correspond to the de-excitation of the first excited state of the target nucleus; for ^{16}O the transition is from the second excited state to the ground state. If the energy spectrum of the interacting particles is known, the cross sections can be used to deduce relative nuclear abundances at the gamma ray source. The abundance analysis will be somewhat complicated by the multiplicity of channels opened up as the incident energies increase. For example, for protons above about 13 MeV, the 4.44-MeV gamma rays from the first excited state of ^{12}C can be produced in the ^{16}O(p,pα)^{12}C reaction, as well as in the ^{12}C(p,p')^{12}C reaction.

The multiplicity of lines from a given target can also be useful. Of special interest are cases where the different gamma-ray lines have different excitation functions, for example the 0.847-MeV gamma rays produced in ^{56}Fe(p,p')^{56}Fe reactions and the 0.812-MeV gamma rays produced in ^{56}Fe(p,n)^{56}Co reactions. The relative yield in such cases can provide insight into the energy spectra of the interacting particles.

INTERNATIONAL ATOMIC ENERGY COMMISSION MEETING IN USE OF
ISOTOPES IN STUDY OF N_2 FIXATION
Vienna, Austria, 1978

Use of ^{13}N in Studies of Fixation of Dinitrogen and Assimilation of Ammonium by Cyanobacteria*

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Denitrification in Soil[1]

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Denitrification has long been of interest to soil scientists since it accounts for a significant loss of fertilizer and soil nitrogen. In the recent past, when nitrogen fertilizer was inexpensive, this loss was compensated for by excessive additions of fertilizer. Today, higher fertilizer costs and limited supplies have rekindled interest in deriving more sound quantitative values of denitrification losses and in elucidating the environmental factors that control those losses with the hope that they might be reduced by proper management. Denitrification, however, remains the least understood transformation in the nitrogen cycle in soils. This is due principally to the absence of sensitive and quantitative techniques for measurement of denitrification rates in nature.

METHODS FOR STUDY OF SOIL DENITRIFICATION

The methods most commonly used to quantitate denitrification in soils are summarized in the following outline.

- I. Field
  - A. Mass balance
    - 1. Lysimeters
    - 2. ^{15}N or ^{14}N
  - B. Cl^-/NO_3^- ratios
- II. Sealed vessels (microcosm)
- III. Packed soil columns
- IV. Enzyme activity
  - A. N_2O reduction
  - B. Acetylene inhibition of N_2O reduction
  - C. $^{13}NO_3^- \rightarrow {}^{13}N_2O + {}^{13}N_2$
- V. Long-term (≥1 day) incubations in flasks

The best quantitative information on denitrification in field soils comes from mass balance studies in which unaccounted-for nitrogen is equated to denitrification. This approach lacks precision and, since it is a long-term average, can never provide information on the importance of the effect of short-term environmental changes, e.g., rain, irrigation, and cultivation, on denitrification. Estimates of fertilizer losses by this approach are generally in the range of 10 to 50% (1, 4, 5, 11). Global balance estimates suggest that denitrification may exceed world fertilizer production by more than five times (3, 5).

Sealed vessels have been used most effectively by Stefanson (13). Rates of denitrification can be more accurately assessed by this method, but the experimental vessels are rather elaborate and can never reproduce natural conditions. Recently, columns packed with soil have become popular, particularly with California scientists (11, 12). This approach has provided important kinetic information on transport and transformation of N forms. The column, however, is basically an enrichment system and is generally operated at steady state, thus limiting its usefulness for aiding understanding of the natural process.

Short-term activity measurements—essentially enzyme assays—hold the greatest promise for new breakthroughs in understanding denitrification, since such methods allow elucidation of direct cause-and-effect relationships between environmental parameters, which can change hourly, daily, or seasonally, and the actual rate of denitrification. Recently, Garcia (8) has used N_2O reduction as a short-term assay. He reported that rates of N_2O reduction observed within 8 h reflect indigenous denitrifying activity and that values after this time reflect denitrification "potential," since de novo enzyme synthesis (and possibly growth) in response to the assay environment has begun to influence the results. A limitation of this method is that NO_3^- and NO_2^- must not be present as competing electron acceptors, and it assumes that rate of N_2O reduction is directly related to rate of N_2O and/or N_2 production.

Very recently, two new methods have been reported which allow even shorter-term activity estimates. One method is the use of acetylene to inhibit N_2O reductase, thereby causing

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[1] Journal article no. 8048 of the Michigan Agricultural Experiment Station.