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"CORRESPONDENCE TRACKING"

TYPE: ACTION  
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DIRECTORATE STATUS

STATUS I

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FROM: ROBBINS, Allen B.: RUTGERS, Department of Physics and Astromony

TO: DR. D.A. BROMLEY

DATE OF  
CORRESPONDENCE: 09/18/91

SUBJECT: REQUEST TO WRITE A CONFIDENTIAL LETTER ASSESSING  
PROFESSOR JOLIE CIZEWSKI, WHO IS BEING CONSIDERED  
FOR A PROMOTION.

\*\*\*\*\*  
DIRECTORATE STAFF  
ASSIGNED: D. Allan Bromley ASSIGNED:

ACTION STAFF  
REQUIRED: AS APPROPRIATE ACTION:

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SENDER'S DUE DATE: 10/08/91  
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| 01a. Letter              | To: Allen Robbins From: Allan Bromley<br>Re: Letter of Recommendation for Jolie Cizewski [personal information redacted] (2 pp.) | 11/8/91 | (b)(6)      |        |

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**File Location:** D. Allan Bromley - Referral [3 of 6] [1991]

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| <b>Date Closed:</b>           | 2/11/2010   | <b>OA/ID Number:</b>        | 62006-003 |
| <b>FOIA/SYS Case #:</b>       | 2005-0336-F | <b>Appeal Case #:</b>       |           |
| <b>Re-review Case #:</b>      |             | <b>Appeal Disposition:</b>  |           |
| <b>P-2/P-5 Review Case #:</b> |             | <b>Disposition Date:</b>    |           |
| <b>AR Case #:</b>             |             | <b>MR Case #:</b>           |           |
| <b>AR Disposition:</b>        |             | <b>MR Disposition:</b>      |           |
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| 01b. Letter              | To: Allan Bromley From: Allen Robbins<br>Re: Requests Letter of Recommendation for Jolie Cizewski<br>[personal information redacted] (1 pp.) | 9/18/91 | (b)(6)      |        |

**Collection:**

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**Subseries:** Correspondence Files  
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| <b>Re-review Case #:</b>      |             | <b>Appeal Disposition:</b>  |           |
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| 01c. Resume              | Resume of Jolie Cizewski [personal information redacted]<br>(20 pp.) |      | (b)(6)      |        |

**Collection:**

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**File Location:** D. Allan Bromley - Referral [3 of 6] [1991]

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| <b>FOIA/SYS Case #:</b>       | 2005-0336-F | <b>Appeal Case #:</b>       |           |
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## DYNAMICAL SYMMETRIES IN A=194 SUPERDEFORMED NUCLEI

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### ABSTRACT

A large number of superdeformed rotational bands in the A=194 region have  $\gamma$ -ray transition energies related to the transition energies of the strongly populated SD band in  $^{192}\text{Hg}$ . These identical structures may be examples of a dynamical supersymmetry involving SU(3) symmetry for the boson core and pseudo-SU(3) symmetry for the valence fermions.

### 1. Introduction

The first candidate<sup>1</sup> for a superdeformed (SD) rotational band in the A=194 mass region was reported in  $^{191}\text{Hg}$ . Since then, there has been an explosion of data in the Hg-Tl-Pb isotopes with as many as 27 SD bands in 13 isotopes in this region.<sup>2-10</sup> The present collaboration has identified SD bands in  $^{192,193,194}\text{Hg}$ ,  $^{194,195}\text{Tl}$ , and  $^{192,194,196,198}\text{Pb}$ ; some of these structures were confirmed in concurrent measurements.

Probably the most exciting aspect of the superdeformed excitations is the observation of SD bands in a large number of nuclei for which the  $\gamma$ -ray transition energies are identical or related to those of the SD band in  $^{192}\text{Hg}$ . For example, in  $^{192}\text{Hg}$  and  $^{194}\text{Pb}$  the SD  $\gamma$ -ray energies are almost identical, with average deviation of <1keV. From naive expectations the moment of inertia should be proportional to  $A^{5/3}$  or a 1.7% difference between  $^{192}\text{Hg}$  and  $^{194}\text{Pb}$ ; the  $\gamma$ -ray energies exhibit a difference of <<1%. Moreover, this example is not isolated. To date 13 bands have been identified in A=194 nuclei which have transition energies related to those of  $^{192}\text{Hg}$  or  $^{193}\text{Tl}$ . These data and the implications for theoretical symmetries will be discussed below.

### 2. Determination of Spins

In a quantum rotor the  $\gamma$ -ray transition energies or angular frequencies  $\hbar\omega \equiv E_\gamma/2$  are:

$$E_\gamma = \hbar^2/2\vartheta [(J+1)(J+2) - (J-1)J] = \hbar^2/2\vartheta (4J+2) \quad (1)$$

$$\hbar\omega = \hbar^2/4\vartheta (4J+2) \Rightarrow \omega = (J+1/2)\hbar/\vartheta \Rightarrow (J+1/2)\hbar = \vartheta\omega \quad (2)$$

To account for the dependence of the moment of inertia on frequency, we have chosen<sup>2,11</sup> to expand the moment of inertia as a function of  $\omega^2$ ,  $\vartheta = \alpha + \beta\omega^2 + \dots$ . The relationship between spin and  $\gamma$ -ray energy or frequency is then

$$(J+1/2)\hbar = \alpha\omega + \beta\omega^3 + \dots \quad (3)$$



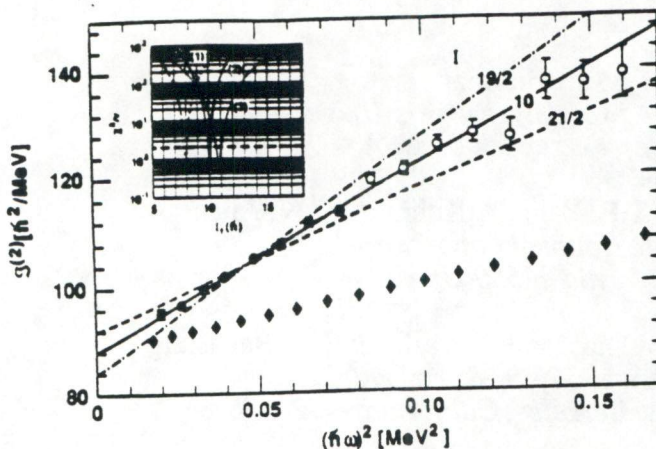


Fig.1 Dynamic moment of inertia  $J^{(2)}$  vs  $\omega^2$  for the strong SD band in  $^{194}\text{Hg}$  and the least-squares fit of  $\gamma$ -ray energies (Eq.3). The insert presents the  $\chi^2/\nu$  for all SD bands in  $^{194}\text{Hg}$ .

in  $^{194}\text{Hg}$  corresponds to a  $12 \rightarrow 10$  transition, the 262-keV  $\gamma$  ray to a  $13 \rightarrow 11$  transition, and the 201-keV  $\gamma$  ray to a  $10 \rightarrow 8$  transition.

### 3. "Identical" band structures

We compared in ref.12 the excited SD bands in  $^{194}\text{Hg}$  to the SD band in  $^{192}\text{Hg}$ . In the case of  $^{194}\text{Hg}$ , the odd-spin excited band has  $\gamma$ -ray energies identical to that of  $^{192}\text{Hg}$ , while its even-spin signature partner has  $\gamma$ -ray energies at the mid-point values. Having determined the spins of these SD excitations, we can examine the behavior of the angular momenta as a function of  $\hbar\omega$ , and the additional angular momentum, or alignment, in a particular band with  $^{192}\text{Hg}$  as reference. In Fig.2 the alignments are displayed for several  $A=194$  SD bands. The surprising result is that the alignment is quantized for at least 8 SD bands in this region and in most cases  $i=1\hbar$ . (If  $^{193}\text{Tl}$  is taken as a reference all 6 SD bands in  $^{194}\text{Tl}$  have alignment  $i=1$  or  $0\hbar$ ).

There are then two aspects of the experimental results which are unexpected and need to be understood: (i) when compared to  $^{192}\text{Hg}$  the identical or related  $\gamma$ -ray energies in a large number of nuclei; (ii) the observed  $i=1\hbar$  alignment, which sets in at moderate rotational frequencies. The remainder of this paper will discuss these observations in terms of dynamical symmetries.

### 4. Dynamical symmetries with pseudo angular momenta

Nuclear shell structure can be approximated with a three-dimensional harmonic oscillator modified by angular momentum and (large) spin-orbit interactions. The large

With 9 to 17 members in a typical SD cascade, we have sufficient data to use Eq.3 to fit the observed  $\gamma$ -ray energies and determine the constants  $\alpha$  and  $\beta$ , and the parameter  $J_f$ , which is the intermediate angular momentum for the lowest  $\gamma$  ray in a given cascade. The details of our spin fits and implications of alternative expressions for determining the spins in SD bands is discussed in ref.11. An example of a spin fit<sup>11</sup> is shown in Fig. 1 for the strong band in  $^{194}\text{Hg}$ . With high confidence the 254-keV  $\gamma$  ray

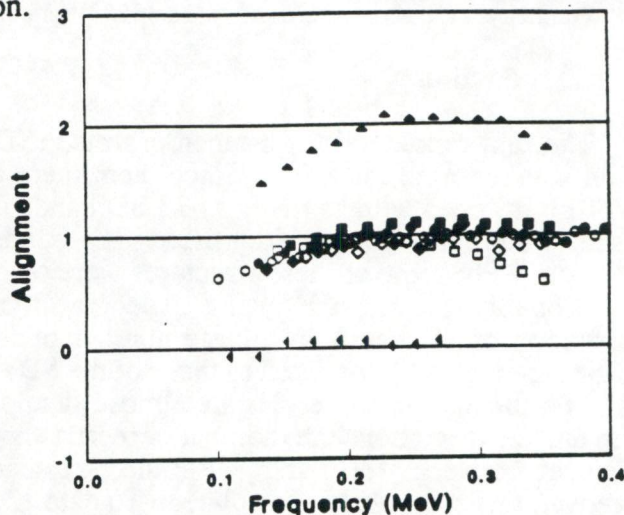


Fig.2 Total aligned angular momentum vs  $\hbar\omega$  for SD  $^{194}\text{Pb}$ ,  $^{191}\text{Hg}^*$ ,  $^{193}\text{Hg}$ ,  $^{194}\text{Hg}^*$ , and  $^{194}\text{Tl}$ . (from ref.12)



$l$ - $s$  interaction gives rise to the observed shell gaps. For example, in the 50-82 shell, most of the orbitals have principal quantum number  $N=4$ . However, the  $N=4$   $g_{9/2}$  orbital occurs below the 50 gap, with the  $N=5$   $h_{11/2}$  orbital in the 50-82 shell. The  $h_{11/2}$  orbital has opposite parity from the other 50-82 shell orbitals, and therefore, does not mix with the  $N=4$  orbitals. The positive-parity orbitals in the 50-82 shell are then a nearly degenerate  $g_{7/2}$ - $d_{5/2}$  pair and a higher lying, nearly degenerate  $d_{3/2}$ - $s_{1/2}$  pair. The total angular momenta of these orbitals is exactly what would be expected for a (pseudo)  $N=3$  shell:  $7/2$ - $5/2$  from pseudo  $l=3$ , and  $3/2$ - $1/2$  from pseudo  $l=1$ . This near degeneracy of orbitals is also true for moderate deformations. For example, the Nilsson orbitals  $5/2^+[402]$  and  $7/2^+[404]$  are nearly degenerate at large deformations near  $Z=82$ ; these become the pseudo-*Nilsson* orbitals  $5/2[303]$  and  $7/2[303]$ . The small spin-orbit interaction in the pseudo harmonic oscillator allows for analytical calculations of the energy spectra and wavefunctions. That such pseudospin or pseudo-SU(3) symmetries may be important in real nuclei was suggested over 20 years ago.<sup>13</sup> More recently, the effects of rotation in pseudo-SU(3) systems has been investigated.<sup>14</sup>

It has been proposed<sup>14</sup> that in a pseudo-SU(3) framework, with no  $l$ - $s$  interaction, the pseudospin of the nucleon can decouple from the pseudo angular momentum and align with the rotation axis of the nucleus at moderate rotation frequencies. Such alignment may explain<sup>12</sup> the observed  $i=1\hbar$  alignment with respect to  $^{192}\text{Hg}$ . In an odd- $A$  nucleus, the total angular momentum is half-integer; as the nucleus rotates, the decoupled pseudospin gives rise to an additional half-unit of angular momentum, for a total  $i=1\hbar$ . In a two-quasiparticle excitation, perhaps the excited SD bands in  $^{194}\text{Hg}$ , the pseudospins of both valence nucleons become aligned. This latter case, however, puts severe constraints on the pseudo-orbitals. For example, with only one pair of degenerate orbitals,  $i=1\hbar$  can only occur for an isolated signature, in contradiction to the data which clearly show  $i=1\hbar$  signature partners. With two signatures, only  $i=0$  can occur for an isolated pair of degenerate orbitals, in contrast with the data. However, with two pairs of degenerate pseudo-*Nilsson* orbitals  $i=1$  bands with both signatures can occur. For the single-neutron orbitals near the  $N=112$  energy gap at large deformations, two pairs of pseudo-*Nilsson* orbitals do exist. However, in realistic calculations (e.g., ref.3b) the second pair has a large pseudospin-orbit splitting with one component far from the Fermi surface. While the pseudo-*Nilsson* scheme can qualitatively explain the observed integer alignments, it cannot explain why we observe "identical" bands in exactly the nuclei in which they occur and, in particular, it has difficulty with a quantitative explanation of the two-quasiparticle excitations in  $^{194}\text{Hg}$ .

It has been suggested<sup>15,16</sup> in an alternative approach that the "identical" structures in superdeformed nuclei are examples of the dynamical supersymmetries that occur in the framework of the Interacting Boson Fermion Approximation (IBFA) model. The beauty of a supersymmetry is that it expects the  $\gamma$ -ray energies in a single fermion nucleus to be related to the  $\gamma$ -ray energies in an even-even nucleus and this symmetry can be extended to two-fermion systems.

Three criteria must be met for a supersymmetry to occur. First, the core structure must be an example of a boson symmetry; the SU(3) boson symmetry applies to these highly deformed nuclei. Second, the valence nucleons must be in specific orbitals, which are part of a complete major shell. Therefore, the valence nucleon cannot occupy a unique-parity orbital, isolated from other orbitals from the same shell. The observed dynamic moments of inertia of the nuclei with structures related to  $^{192}\text{Hg}$  indicate that the valence particle is not in a unique-parity configuration. The requirement of a complete shell is met if one exploits the pseudo-harmonic oscillator. While most tests of boson-fermion symmetries have assumed that the core structure is dominated by  $s$  and  $d$  bosons, and that the valence particle occupies a limited number of low-spin orbitals, the



present study requires no such restrictions. The boson  $SU(3)$  symmetry is realized for many boson systems, and the fermion spectra take on one of three generic forms.<sup>16</sup> For a boson-fermion symmetry the energies of the even and odd mass nuclei are:<sup>16</sup>

$$E_{\text{even}} = A^e + B^e L(L+1) \quad (4)$$

$$E_{\text{odd}} = A^o + B^o L(L+1) + C J(J+1) \quad (5)$$

where the parameters  $A$  affect the band-head energies, and the excitation energies depend upon an integer orbital angular momentum,  $L$ , and, for the odd- $A$  system, total angular momentum,  $J$ . The third requirement for a supersymmetry is that  $B^e=B^o$ . Identical  $\gamma$ -ray energies occur when  $C=0$ , which is a further restriction of the symmetry. One of the three generic types of level diagrams expected in a supersymmetry description of an odd- $A$  nucleus is shown in Fig. 3. (The other two types involve decoupled bands which would not give rise to the signature pairs that characterize the  $A \approx 194$  related structures).

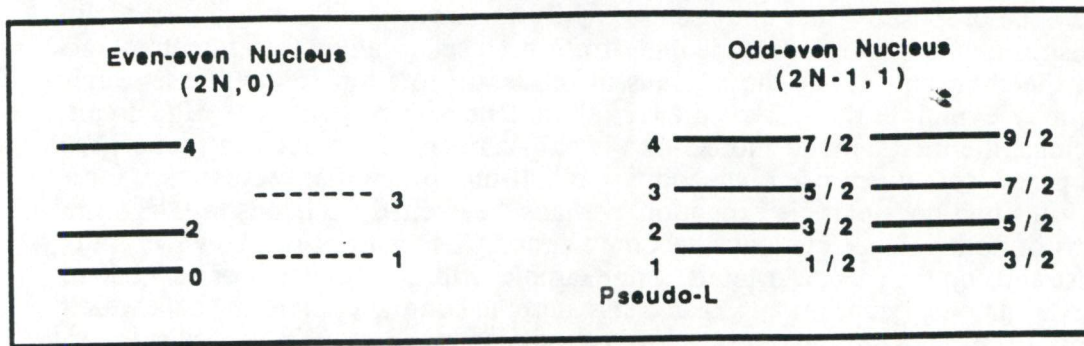


Fig. 3 Strong-coupled spectra for even and odd- $A$  nuclei with  $SU(3)$  supersymmetry.

A comparison between experiment and supersymmetry predictions (with  $C=0$ ) of the angular momenta as a function of frequency ( $=E_\gamma/2$ ) is presented in Fig. 4. At first glance the figures look quite similar. Unfortunately, the observed alignment  $i=1\hbar$  cannot be reproduced with  $C=0$ ; the theory gives  $i=\pm 0.5\hbar$ .

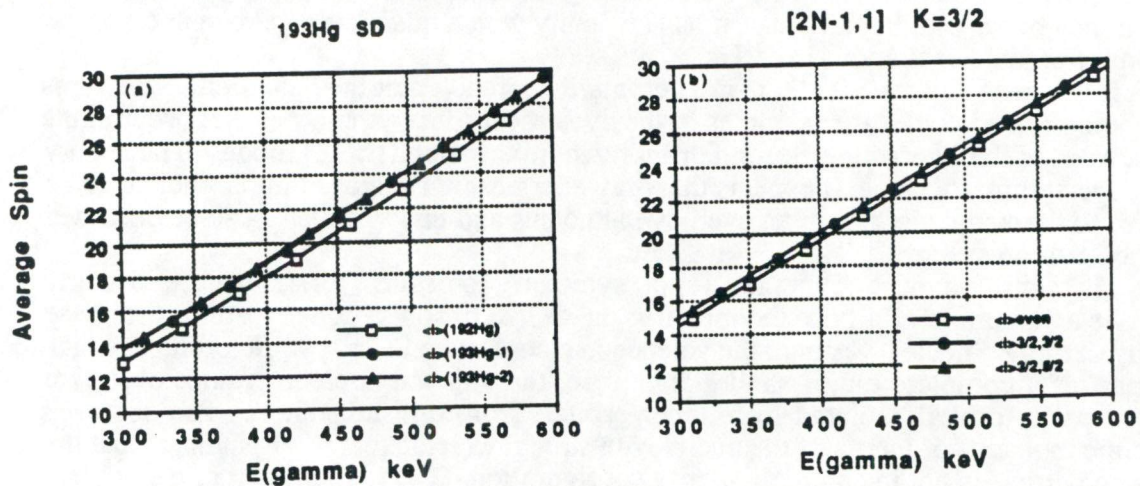


Fig. 4 (a) Spin vs  $E_\gamma$  for the strong-coupled bands in  $^{193}\text{Hg}$  and the  $^{192}\text{Hg}$  reference (refs.2,4)  
(b) Spin vs  $E_\gamma$  for the supersymmetric  $K=3/2$  and reference bands with  $C=0$ .



The experimental dynamic moments of inertia exhibit a strong dependence on the rotational frequency. In the present analysis we have assumed that the frequency dependence on the B parameters is identical in the even and odd A nuclei. However, the frequency dependence on the parameter C is an open question. Also, to date no analytical expression for a two-fermion supersymmetry has been derived, partly because the data in  $^{194}\text{Hg}$  may be the first candidate for such a symmetry. We are in the process of determining how alignment  $i=1.0\hbar$  could be achieved, and examining the parameter choices to ensure that they are appropriate for a range of nuclei with structures related to  $^{192}\text{Hg}$ .

## 5. Conclusions

A large number of superdeformed bands in  $A\approx 194$  nuclei show related structures. In even-even nuclei, the  $\gamma$ -ray energies are identical to, or at the mid-point values, of the  $\gamma$ -ray energies of SD  $^{192}\text{Hg}$ . In odd-A nuclei the  $\gamma$ -ray energies occur at the "quarter points." The observed pattern of  $\gamma$ -ray energies and the extracted spins of these excitations indicate that the alignment with respect to  $^{192}\text{Hg}$  is quantized, frequently with  $i=1.0\hbar$ . The simplicity of these data are a signature of a symmetry, and most probably a symmetry involving pseudo angular momenta, such as a pseudospin symmetry or the more restrictive supersymmetry. Additional theoretical development will be necessary to understand more fully these simple structures.

The study of superdeformed excitations and their possible symmetries is a frontier area of nuclear structure study. The limits of the N and Z values of superdeformed shapes in  $A\approx 194$  nuclei have not been established. Very few of the excited structures in the superdeformed minima have been observed; the present measurements are at the limit of current experimental techniques. With the next generation of gamma-ray detector arrays the ability to study excitations in superdeformed nuclei will be greatly enhanced.

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## SINGLE-PARTICLE AND COLLECTIVE EXCITATIONS IN $^{124}\text{Te}$

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**Abstract:** Low-lying excitations in  $^{124}\text{Te}$  have been investigated using the  $^{122}\text{Sn}(\alpha, 2n)$  reaction at beam energies of 21 and 23 MeV. Standard in-beam spectroscopy techniques of excitation function,  $\gamma\gamma$ -coincidence and  $\gamma$ -ray angular distribution measurements were used. A level scheme up to 3410 keV was constructed. Nine new  $\gamma$ -rays have been placed and definite spin-parity assignments were made to a number of new levels. Among the new states identified were possible  $10^+$  and  $8^+$  members of the ground-state quasiband. To test proposed collective properties, non-yrast states populated in this work are examined through their relative  $B(E2)$  values and mixing ratios. No evidence supporting the existence of strong intruder components has been found.

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NUCLEAR REACTIONS:  $^{122}\text{Sn}(\alpha, 2n)$   $E = 18\text{--}23$  MeV; measured  $E_\gamma$ ,  $I_\gamma(E)$ ,  $I_\gamma(\theta)$ ,  $\gamma\gamma$ -coin.  $^{124}\text{Te}$  deduced levels,  $J$ ,  $\pi$ ,  $\delta(E2/M1)$ . Model comparison.  
NUCLEAR STRUCTURE: Vibrational collective excitations, 4p2h intruders, mixed-symmetry, interacting-boson model.

### 1. Introduction

In recent years  $^{124}\text{Te}$  has been one of the most extensively studied even-mass Te isotopes. With two protons outside the  $Z = 50$  shell closure and ten valence neutrons,  $^{124}\text{Te}$  is expected to be of transitional character, presenting an example of the onset of collective motion, with the inherent interplay between collective and single-particle excitations, as well as providing a bridge between vibrational and more deformed collective motions. Recent  $\beta$ -decay<sup>1-3)</sup> and thermal-neutron capture reaction<sup>4)</sup> studies have provided new spectroscopic information on the low-spin states. The low-lying low-spin structure has suggested that  $^{124}\text{Te}$  may be a  $\gamma$ -unstable nucleus, within the framework of the interacting boson approximation (IBA) and dynamic deformation (DDM)<sup>5-7)</sup> models, the latter showing that particle-like protons and hole-like neutrons stabilize the nucleus into a deformed shape with  $\beta \approx 0.2$ . These previous results have led to the suggestion that  $^{124}\text{Te}$  may even be a good example of the IBA O(6) dynamical symmetry<sup>8)</sup>.

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However, level energies predicted from these  $\gamma$ -unstable models do not reproduce the experimental results for many of the non-yrast states, and have even less success in reproducing the reduced transition probabilities and the electric quadrupole moment of the  $2_1^+$  state. Ignoring any possible mixing with valence single-particle excitations, the low-lying collective states could be mixed with an intruder configuration<sup>9)</sup>, an excitation of two protons across the  $Z = 50$  shell closure. IBA-2 calculations<sup>10)</sup> which take into account such mixing between intruder and normal configurations result in better agreement with the experimental observables. Previous measurements aimed at identifying the role of intruder configurations have been largely concerned with the location of the excited  $0^+$  states in lighter ( $A \leq 122$ ) Te isotopes, using conversion electron measurements<sup>11-13)</sup>. Even in these lighter isotopes, the existence of intruder states is still controversial. For heavier Te isotopes, one expects a possible intruder band head to be shifted up in energy<sup>9)</sup>, making the efforts to find intruder states in  $^{124}\text{Te}$  even more formidable, given the increasing level density and the energy-favored decay out of any intruder band. Therefore, we have taken a different approach in studying the role of intruders in  $^{124}\text{Te}$ . A  $\Delta I = 2$  band built upon the first excited  $0_2^+$  state has been previously proposed as an intruder band<sup>10)</sup>. While this "band" does not follow an  $I(I+1)$  energy spacing, the distortion could possibly be understood by mixing with normal states. However, no intraband transitions for  $I \leq 8^+$  states have been observed. Our present measurements included a search for these intraband transitions. By examining the ratio of reduced transition probabilities among the higher spin near-yrast states, we hope to provide additional insight into the role of intruders in  $^{124}\text{Te}$ .

In the present paper we have used the relatively non-selective ( $\alpha, 2n$ ) reaction to obtain additional spectroscopic information on non-yrast excitations in  $^{124}\text{Te}$ . After discussing the level spectrum we have obtained, we shall discuss the collective properties of low-lying ( $E_x < 2$  MeV) states in terms of various model predictions, and the additional insight we have gained on the role of intruder configurations. We shall also discuss in terms of two quasineutron excitations the negative-parity states we have identified.

## 2. Experimental procedure and measurements

The nucleus  $^{124}\text{Te}$  was populated with an  $\alpha$ -induced fusion evaporation reaction  $^{122}\text{Sn}(\alpha, 2n)$  at the Rutgers FN tandem Van de Graaff accelerator. An isotopically enriched  $^{122}\text{Sn}$  target (92.20% purity), 2.8 mg/cm<sup>2</sup> thick, was evaporated directly onto a 0.5 mm thick slab of Pb. Standard  $\gamma$ -ray spectroscopy, including  $\gamma$ -ray excitation function,  $\gamma$ -ray angular distribution, and  $\gamma\gamma$ -coincidence measurements, was carried out. In the  $\gamma\gamma$ -coincidence measurements three germanium detectors were used with typical energy resolutions of 2.2 keV at 1332 keV: two n-type high-purity coaxial detectors with an efficiency of 25% and a Ge(Li) detector with an efficiency of 20%, relative to a  $7.5 \times 7.5$  cm<sup>2</sup> NaI detector.



Gamma-ray excitation functions were measured for beam energies of 18–23 MeV in 0.5 MeV steps using a single germanium detector. The relative yields of each transition as a function of beam energy were extracted, normalized to the integrated beam current. The favorable beam energies for the present work were chosen to be 21 and 23 MeV. The lower energy was used to yield higher cross sections for population of low-lying non-yrast states.

The angular distribution measurements were performed with an  $\alpha$ -energy of 23 MeV. The  $\gamma$ -ray yields were collected with two detectors; a Ge detector was kept at  $-90^\circ$  to the beam direction for normalization. The other high-purity germanium detector was swept between the angles of  $0^\circ$  and  $90^\circ$  in  $15^\circ$  steps. Another set of data, taken with the same germanium detector shielded with a BGO Compton-suppression shield, was also obtained. These data provided complementary information on the weak transition intensities, in particular for  $E_\gamma \leq 500$  keV. The data at different angles were normalized to the yield of the 602.7 keV,  $2^+ \rightarrow 0^+$  transition in the fixed detector, and were then efficiency corrected. Efficiencies as a function of angle were obtained by placing <sup>133</sup>Ba and <sup>152</sup>Eu sources at the target position. The peak areas as a function of angle were fitted with a fourth-order truncated Legendre polynomial

$$W(\theta) = I_\gamma [1 + A_2 P_2(\cos \theta) + A_4 P_4(\cos \theta)].$$

The solid-angle correction for the present detection configuration was  $Q_2 = 0.99$ ,  $Q_4 = 0.98$ , nearly independent of  $\gamma$ -ray energy. Angular distribution coefficients and the extracted  $\gamma$ -ray intensities are summarized in table 1; table 2 shows more precise values with errors and placement in the level scheme.

To assign multiplicities to all transitions, the alignment attenuation coefficients (<sup>14</sup>),  $\alpha_2$ , were extracted using the method described in ref. <sup>15</sup>). The measured angular distribution coefficients for known stretched E1, M1 and E2 transitions were compared to theoretical predictions to extract the gaussian widths of the population. For our measurements, the extracted widths ranged from 0.2 to 0.3 per unit of angular momentum, and  $\alpha_2 > 0.6$  for most of the transitions. This indicates that considerable alignment is preserved as the nucleus deexcites, thus aiding the assignment of multiplicities of stretched transitions and determination of E2/M1 ratios for mixed transitions.

In the  $\gamma\gamma$ -coincidence measurements events were recorded on magnetic tapes using three germanium detectors placed at  $50^\circ$ ,  $102^\circ$ , and  $-105^\circ$  with respect to the beam direction. An event consisted of one time-to-amplitude convertor (TAC) signal and two  $\gamma$ -ray energy signals. The time resolutions of all three TAC spectra were about 20 ns (FWHM). The data were first analyzed by sorting 15.5 million real, prompt events into a  $2048 \times 2048$  matrix. Fig. 1 shows a projected spectrum of the coincidence matrix at  $E_\alpha = 21$  and 23 MeV. Background-subtracted spectra gated on selected transitions, including the 602.7 keV  $2^+ \rightarrow 0^+$  transition, are shown in fig. 2.



TABLE I  
Summary of the angular distribution results for transitions in <sup>124</sup>Te

| $E_\gamma$ (keV) <sup>a)</sup> | $I_\gamma$ <sup>b)</sup> | $A_2$ <sup>c)</sup> | $A_4$ <sup>c)</sup> | Multipolarity | $\delta(E2/M1)$ <sup>d)</sup> |
|--------------------------------|--------------------------|---------------------|---------------------|---------------|-------------------------------|
| 329.3                          | 24 (1)                   | -0.66 (9)           | 0.13 (11)           | E2+M1         | $-2.10^{+0.60}_{-0.35}$       |
| 359.1                          | 30 (5)                   | 0.30 (5)            | 0                   | (E2)          |                               |
| 443.8                          | 11 (2)                   | -0.42 (24)          | -0.36 (41)          | E2+M1         | $-10 < \delta < -0.1$         |
| 472.1                          | 12 (1)                   | 0.41 (10)           | -0.20 (16)          | E2            |                               |
| 489.9                          | 62 (2)                   | 0.43 (4)            | -0.19 (6)           | E2            |                               |
| 498.3                          | 516 (19)                 | 0.35 (4)            | -0.12 (6)           | E2            |                               |
| 525.4                          | 7 (1)                    | -0.01 (17)          | 0.08 (25)           | (E2+M1)       | $-1.1^{+0.5}_{-0.9}$          |
| 602.7                          | 1000 (25)                | 0.33 (4)            | -0.14 (6)           | E2            |                               |
| 645.9                          | 793 (28)                 | 0.35 (4)            | -0.15 (6)           | E2            |                               |
| 677.4                          | 28 (1)                   | 0.38 (5)            | -0.17 (8)           | E2            |                               |
| 697.5                          | 45 (2)                   | 0.33 (4)            | -0.15 (6)           | E2            |                               |
| 709.5                          | 24 (1)                   | 0.04 (6)            | -0.13 (8)           | E2+M1         |                               |
| 713.9                          | 15 (1)                   | -0.09 (7)           | -0.10 (10)          | E2+M1         |                               |
| 723.1                          | 38 (2)                   | -0.10 (4)           | -0.15 (7)           | E2+M1         |                               |
| 745.1                          | 18 (1)                   | -0.09 (7)           | -0.10 (9)           | (E2+M1)       |                               |
| 791.1                          | 9 (1)                    | 0.19 (7)            | -0.02 (17)          | (E2)          |                               |
| 886.2                          | 18 (1)                   | 0.13 (7)            | -0.18 (10)          | E2+M1         | $-1.0 \pm 0.9$                |
| 918.1                          | 206 (6)                  | 0.35 (2)            | -0.19 (3)           | E2            |                               |
| 927.3                          | 117 (3)                  | -0.22 (2)           | 0                   | E1            |                               |
| 976.9                          | 11 (1)                   | 0.02 (9)            | -0.24 (13)          | E2+M1         |                               |
| 1086.5                         | 85 (3)                   | -0.20 (3)           | 0                   | E1            |                               |
| 1101.2                         | 29 (1)                   | 0.34 (5)            | -0.07 (8)           | E2            |                               |
| 1126.5                         | 25 (1)                   | -0.90 (5)           | 0.10 (6)            | E2+M1         |                               |
| 1301.7                         | 11 (1)                   | -0.03 (12)          | 0.00 (17)           | (isotropic)   |                               |
| 1325.8                         | 13 (1)                   | 0.15 (6)            | 0                   | (E2)          |                               |
| 1346.3                         | 10 (1)                   | -0.80 (11)          | 0.11 (14)           | E2+M1         |                               |
| 1355.4                         | 25 (1)                   | 0.16 (6)            | -0.09 (8)           | (E2)          | $-1.0 \pm 0.9$                |
| 1437.0                         | 22 (1)                   | 0.11 (6)            | -0.11 (10)          | E2+M1         |                               |
| 1488.9                         | 17 (1)                   | 0.09 (7)            | -0.21 (11)          | E2+M1         |                               |
| 1525.8                         | 9 (1)                    | 0.16 (16)           | -0.11 (28)          | (E2+M1)       |                               |
| 1690.7                         | 10 (1)                   | -0.18 (13)          | 0                   | E1            |                               |

<sup>a)</sup> Energies are rounded to the first decimal point. See table 2 for more precise values with errors.

<sup>b)</sup> All intensities are normalized to the intensity of the 602.7 keV  $\gamma$ -ray. Errors on the last digits are only statistical uncertainties coming from the fitting of peak areas.

<sup>c)</sup> Large uncertainties are due to weak intensities for  $I_\gamma \leq 15$ .

<sup>d)</sup> For small  $A_2$  or  $A_4$  coefficients, which also have relatively large uncertainties, no attempt was made to determine mixing ratios.

### 3. Results and level scheme

Combining the results of the  $\gamma\gamma$ -coincidence and angular distribution measurements, we constructed a level scheme up to 3410.2 keV in excitation, as shown in fig. 3. The present spectrum was based on the compilation of ref. <sup>16)</sup> and the results of neutron capture <sup>4)</sup>, and  $\beta$ -decay (<sup>124</sup>Sb) measurements in refs. <sup>1-3)</sup>. The four low-lying 2<sup>+</sup> states at 602.7, 1325.8, 2039.7 and 2091.6 keV were all found in the present work, and will be discussed in the framework of collective models. The



TABLE 2  
Placement of transitions in <sup>124</sup>Te from ( $\alpha$ , 2n) measurements

| $E_\gamma$ (keV) <sup>a)</sup> | $E_i$ (keV) | $E_f$ (keV) | $I_i^\pi - I_f^\pi$                               |
|--------------------------------|-------------|-------------|---------------------------------------------------|
| 329.27 (8)                     | 2664.4      | 2335.1      | 6 <sup>-</sup> -5 <sup>-</sup>                    |
| 359.09 (8)                     | 3033.3      | 2674.1      | ?-7 <sup>-</sup>                                  |
| 443.8 (2)                      | 2483.5      | 2039.7      | 2 <sup>+</sup> -2 <sup>+</sup>                    |
| 472.08 (10)                    | 3137.1      | 2665.0      | 10 <sup>+</sup> -8 <sup>+</sup>                   |
| 489.89 (10)                    | 3154.9      | 2665.0      | 10 <sup>+</sup> -8 <sup>+</sup>                   |
| 498.3 (2)                      | 1746.9      | 1248.6      | 6 <sup>+</sup> -4 <sup>+</sup>                    |
| 525.37 (11)                    | 2483.5      | 1958.1      | (2 <sup>+</sup> , 3 <sup>+</sup> )-4 <sup>+</sup> |
| 602.68 (12)                    | 602.7       | 0           | 2 <sup>+</sup> -0 <sup>+</sup>                    |
| 645.90 (16)                    | 1248.6      | 602.7       | 4 <sup>+</sup> -2 <sup>+</sup>                    |
| 677.37 (11)                    | 3351.6      | 2674.2      | 9 <sup>-</sup> -7 <sup>-</sup>                    |
| 697.5 (2)                      | 2444.4      | 1746.9      | 8 <sup>+</sup> -6 <sup>+</sup>                    |
| 709.54 (14)                    | 1958.1      | 1248.6      | 4 <sup>+</sup> -4 <sup>+</sup>                    |
| 713.95 (14)                    | 2039.7      | 1325.8      | 2 <sup>+</sup> -2 <sup>+</sup>                    |
| 723.07 (15)                    | 1325.8      | 602.7       | 2 <sup>+</sup> -2 <sup>+</sup>                    |
| 745.12 (15)                    | 3410.2      | 2665.0      | 9-8 <sup>+</sup>                                  |
| 791.1 (2)                      | 2039.7      | 1248.6      | 2 <sup>+</sup> -4 <sup>+</sup>                    |
| 886.23 (18)                    | 2134.8      | 1248.6      | 4 <sup>+</sup> -4 <sup>+</sup>                    |
| 918.1 (2)                      | 2665.0      | 1746.9      | 8 <sup>+</sup> -6 <sup>+</sup>                    |
| 927.26 (20)                    | 2674.2      | 1746.9      | 7 <sup>-</sup> -6 <sup>+</sup>                    |
| 976.92 (20)                    | 2225.5      | 1248.6      | 4 <sup>+</sup> -4 <sup>+</sup>                    |
| 1086.5 (2)                     | 2335.1      | 1248.6      | 5 <sup>-</sup> -4 <sup>+</sup>                    |
| 1101.18 (22)                   | 2349.8      | 1248.6      | 6 <sup>+</sup> -4 <sup>+</sup>                    |
| 1126.46 (22)                   | 2873.3      | 1746.9      | 7 <sup>+</sup> -6 <sup>+</sup>                    |
| 1301.66 (25)                   | 2550.3      | 1248.6      | ?-4 <sup>+</sup>                                  |
| 1325.8 (3)                     | 1325.8      | 0           | 2 <sup>+</sup> -0 <sup>+</sup>                    |
| 1346.31 (25)                   | 2594.9      | 1248.6      | 5 <sup>+</sup> -4 <sup>+</sup>                    |
| 1355.4 (3)                     | 1958.1      | 602.7       | 4 <sup>+</sup> -2 <sup>+</sup>                    |
| 1437.0 (3)                     | 2039.7      | 602.7       | 2 <sup>+</sup> -2 <sup>+</sup>                    |
| 1488.9 (3)                     | 2091.6      | 602.7       | 2 <sup>+</sup> -2 <sup>+</sup>                    |
| 1525.83 (25)                   | 2774.4      | 1248.6      | (3, 4)-4 <sup>+</sup>                             |
| 1690.70 (30)                   | 2293.4      | 602.7       | 3 <sup>-</sup> -2 <sup>+</sup>                    |

<sup>a)</sup> Errors on the last digits are a combination of uncertainties coming from peak fitting and energy calibration.

ground-state band (g.s.b.) is connected by strong E2 intraband transitions, while the quasiband, to the right of the g.s.b. in fig. 3, deexcites via interband transitions to the members of the g.s.b. The two excited 0<sup>+</sup> states previously identified<sup>4)</sup> at 1657 and 1883 keV were not observed in the present work. The negative-parity states are grouped together to the left of the g.s.b.

We have identified seven new  $\gamma$ -rays in the present work at 329.3, 472.1, 677.4, 697.5, 745.1, 886.2, and 1346.3 keV. Two previously observed transitions, the 359.1 keV  $\gamma$ -ray seen in an ( $\alpha$ , 2n) study<sup>17)</sup> and the 1301.7 keV  $\gamma$ -ray seen in  $\beta$ -decay<sup>3)</sup>, were also confirmed. The 359.1 keV  $\gamma$ -ray deexcites a new level at 3033.3 keV to the 7<sup>-</sup> state at 2674.2 keV, as is evident in the gated spectra shown in fig. 2. Our placement of the level at 2550.2 keV from coincidence data of the

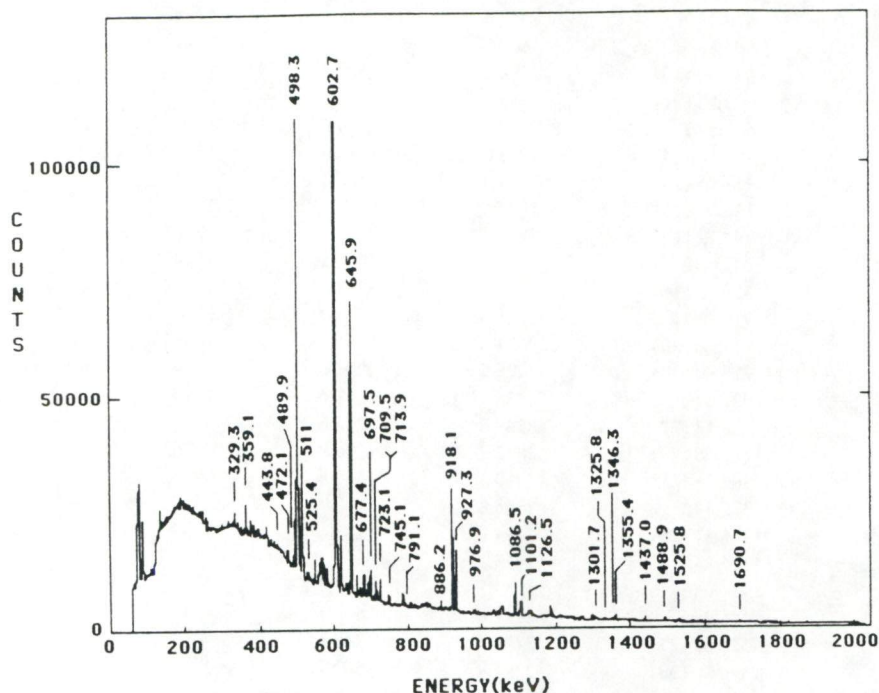


Fig. 1. Total-projected spectrum of the coincidence measurements in the  $^{122}\text{Sn}(\alpha, 2n)$  reaction at  $E_\alpha = 21$  and 23 MeV

1301.7 keV  $\gamma$ -ray agrees with the result of ref. <sup>3</sup>). New findings, including eight new levels, are summarized in table 3.

The angular distribution results show that the 472.1, 677.4, and 697.5 keV  $\gamma$ -rays are stretched E2 transitions, deexciting to  $8^+$ ,  $7^-$ , and  $6^+$  states, respectively. The 329.3, 1126.5, and 1346.3 keV transitions all have similar angular distributions with large negative  $A_2$  coefficients, characteristic of mixed E2 + M1 transitions with  $\Delta I = 1$ . The angular distribution of the 745.1 keV  $\gamma$ -ray deexciting the level at 3410.2 keV resembles a mixed transition; however, the large uncertainties in both  $A_2$  and  $A_4$  coefficients indicate that the transition may also be of dipole type, possibly an E1 transition to the  $8^+$  state at 2665.0 keV in the g.s.b. A negative-parity assignment is favored as the other odd-spin, negative-parity states, the  $3^-$ ,  $5^-$ , and  $7^-$  states, all show E1 interband transitions to the  $2^+$ ,  $4^+$ , and  $6^+$  states in the g.s.b.

#### 4. Discussion

In the simplest configuration of valence particles in  $^{124}\text{Te}$ , two protons occupy the  $\pi d_{5/2}$  and  $\pi g_{7/2}$  orbitals while the twenty-two neutrons fill the lower  $\nu d_{5/2}$  and  $\nu g_{7/2}$  orbitals and half fill the  $\nu h_{11/2}$  orbital. For the yrast members in the g.s.b., the  $2^+$  state is the lowest-lying collective excitation. The constant energy systematics



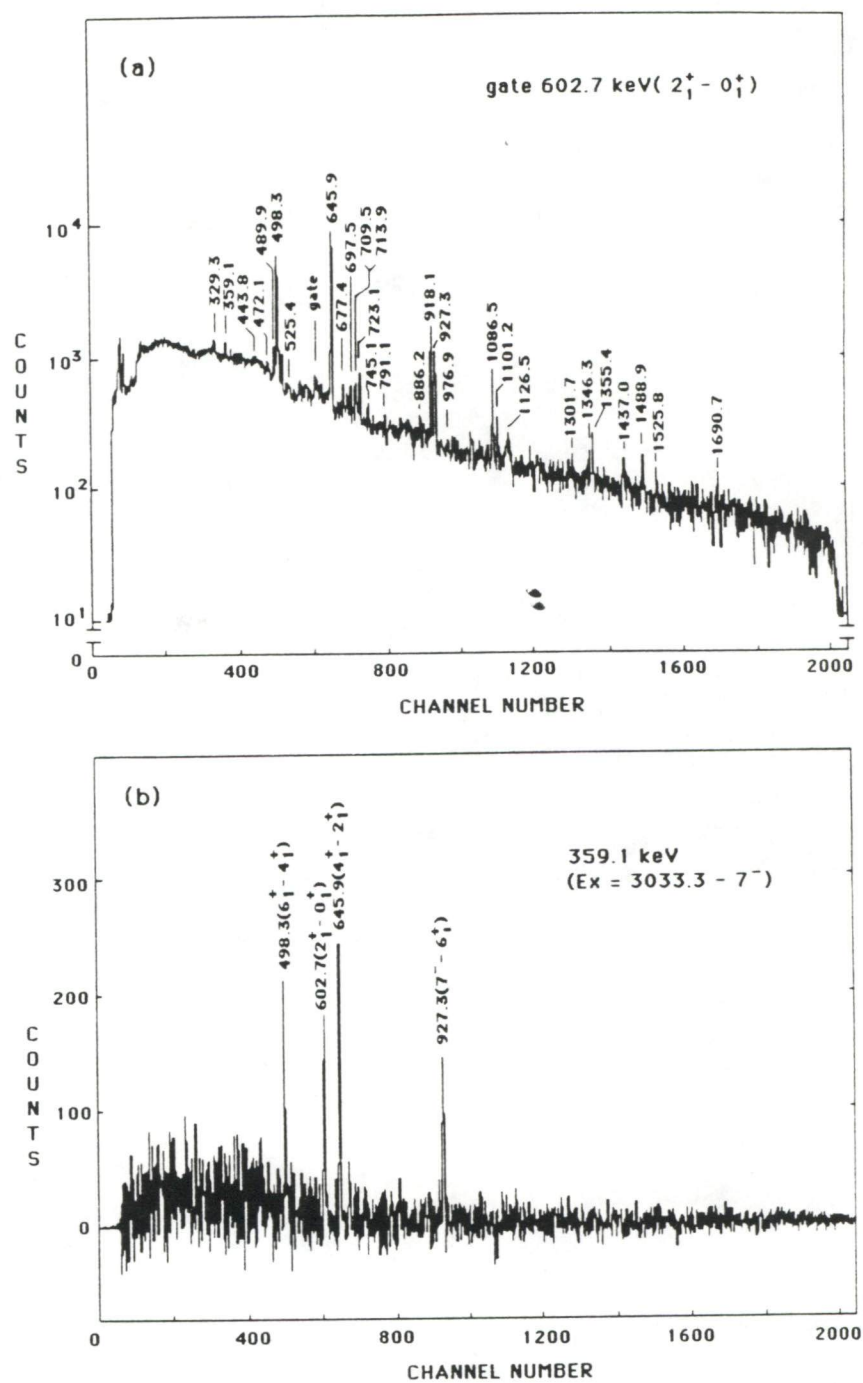


Fig. 2. Background-subtracted spectra gated on the (a) 602.7 keV, (b) 359.1 keV, (c) 927.1 keV, and (d) 745.1 keV transitions.

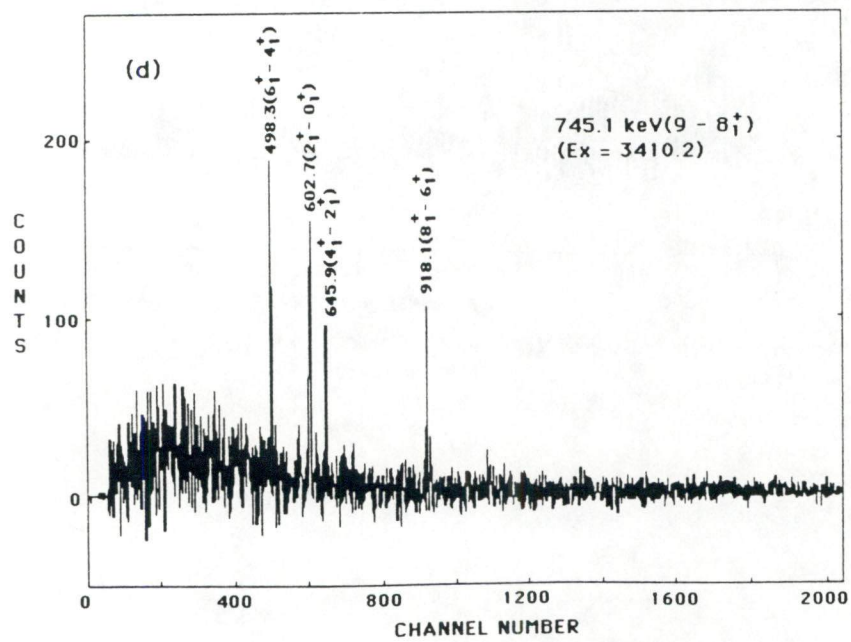
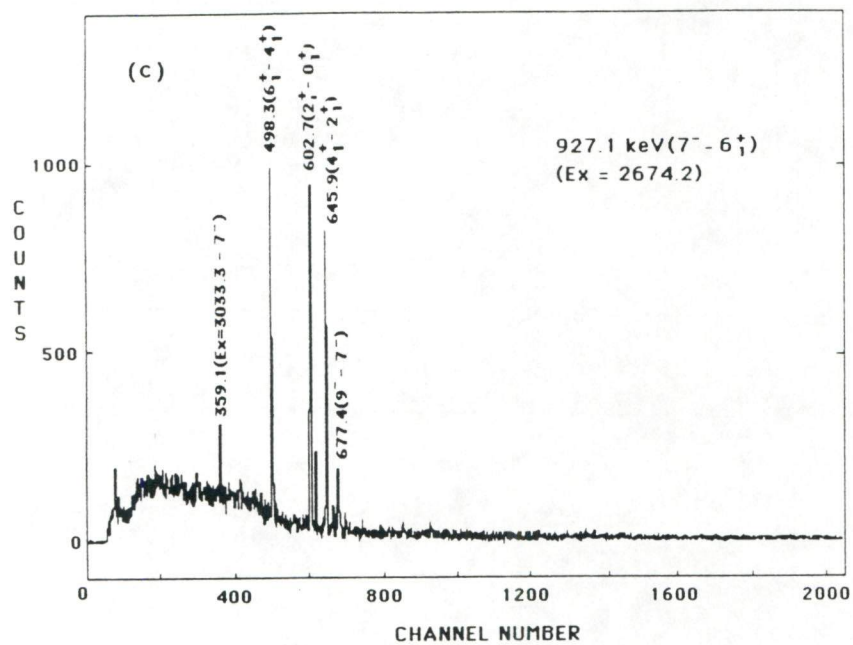


Fig. 2—continued



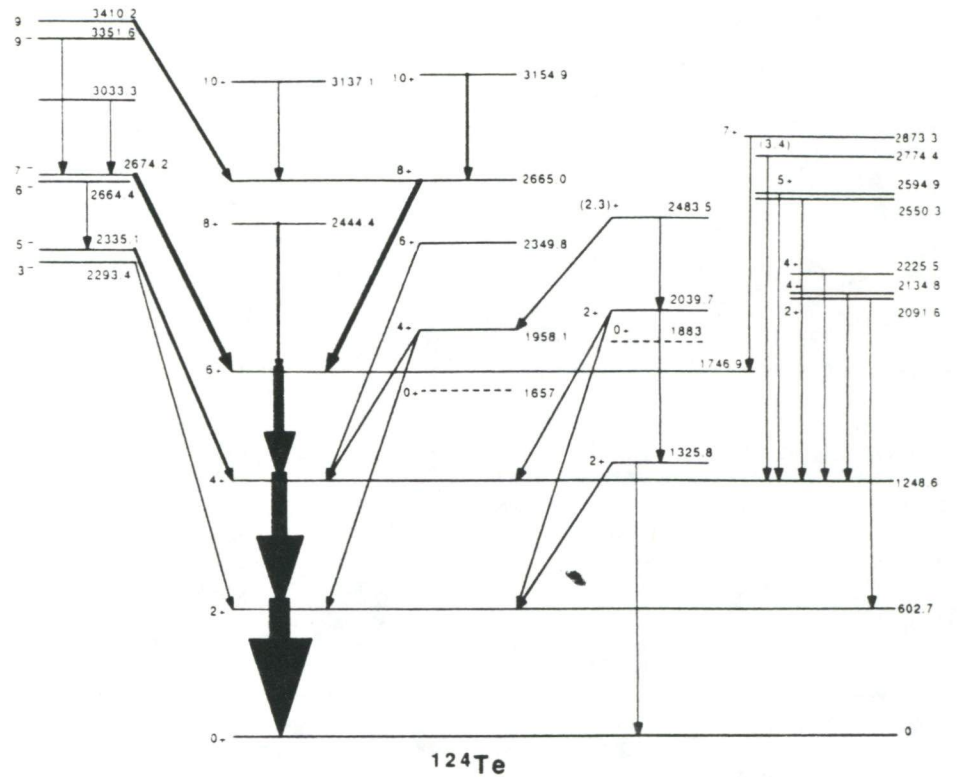


Fig. 3. Level spectrum of  $^{124}\text{Te}$ . The widths of the arrows are approximately proportional to the intensities of the  $\gamma$ -rays. Dotted levels were not observed in the present work, but are taken from ref. <sup>4</sup>).

(fig. 4) as a function of neutron number suggest that the  $6^+$  state has significant two-proton components, namely  $(\pi g_{7/2})^2$  or  $(\pi d_{5/2} \otimes \pi g_{7/2})$ . While the yrast  $4^+$  state is probably predominantly a collective excitation, it probably also has a sizeable admixture of two-proton structure. The higher-spin states  $I \geq 8^+$  in the g.s.b. probably involve quasineutron excitations, with a major contribution from  $(\nu h_{11/2})^2$  components.

#### 4.1. COLLECTIVITY OF NON-YRAST STATES $\leq 2$ MeV

In order to study the structure of  $^{124}\text{Te}$  we have examined the collective properties of the non-yrast states by comparing reduced transition probabilities. In fig. 5 the extracted relative E2 branching ratios are shown and summarized in table 4, along with theoretical predictions from various models. The  $2_2^+$  state resembles the normal collective state of either a vibrational or  $\gamma$ -unstable nucleus. The  $2_3^+$  state also seems to be of predominantly collective nature. The finite  $B(E2)$  ratio  $(2_3^+ \rightarrow 2_2^+) / (2_3^+ \rightarrow 4_1^+)$  supports a vibrational interpretation, near the theoretical value of 0.56 in the  $SU(5)$

TABLE 3  
Summary of new results in  $^{124}\text{Te}$

| $E_\gamma$ (keV)           | $I_\gamma(\%)^a$ | $E_i$                | $E_f$  | $I_i^\pi - I_f^\pi$ | Multipolarity | $\delta$                |
|----------------------------|------------------|----------------------|--------|---------------------|---------------|-------------------------|
| 329.27 (8)                 | 2.4 (1)          | 2664.4 <sup>b)</sup> | 2335.1 | $6^- - 5^-$         | E2 + M1       | $-2.10^{+0.60}_{-0.35}$ |
| 359.09 (8) <sup>c)</sup>   | 3.0 (5)          | 3033.3               | 2674.2 | $? - 7^-$           | (E2)          |                         |
| 472.08 (10)                | 1.2 (1)          | 3137.1               | 2665.0 | $10^+ - 8^+$        | E2            |                         |
| 677.37 (11)                | 2.8 (1)          | 3351.6 <sup>d)</sup> | 2674.2 | $9^- - 7^-$         | E2            |                         |
| 697.5 (2)                  | 4.5 (2)          | 2444.4 <sup>e)</sup> | 1746.9 | $8^+ - 6^+$         | E2            |                         |
| 745.12 (15)                | 1.8 (1)          | 3410.2               | 2665.0 | $9 - 8^+$           | (E2 + M1)     |                         |
| 886.23 (18)                | 1.8 (1)          | 2134.8               | 1248.6 | $4^+ - 4^+$         | E2 + M1       |                         |
| 1301.66 (25) <sup>f)</sup> | 1.1 (1)          | 2550.3 <sup>g)</sup> | 1248.6 | $? - 4^+$           | (isotropic)   |                         |
| 1346.31 (25)               | 1.0 (1)          | 2594.9 <sup>h)</sup> | 1248.6 | $5^+ - 4^+$         | E2 + M1       | $-1.0 \pm 0.9$          |

<sup>a)</sup> Intensities measured relative to the 602.7 keV  $\gamma$ -ray.

<sup>b)</sup> A 2663 (6) keV level was previously seen in the  $^{123}\text{Te}(d, p)$  reaction of ref. <sup>18)</sup>.

<sup>c)</sup> This  $\gamma$ -ray was not placed in ref. <sup>17)</sup>; a 358.79 keV transition in ref. <sup>2)</sup> was placed depopulating the 2694.04 keV level. We do not confirm this latter assignment.

<sup>d)</sup> A 3360 (20) keV level was previously observed in the  $^{126}\text{Te}(p, t)$  reaction of ref. <sup>19)</sup>.

<sup>e)</sup> A 2444 (15) keV level was previously observed in the  $^{125}\text{Te}(p, d)$  reaction of ref. <sup>20)</sup>.

<sup>f)</sup> A 1301.7 keV  $\gamma$ -ray was recently identified in ref. <sup>3)</sup>.

<sup>g)</sup> A 2550 (15) keV level was previously observed in the  $^{126}\text{Te}(p, t)$  reaction of ref. <sup>19)</sup> and also at 2550.2 keV in ref. <sup>3)</sup>.

<sup>h)</sup> A 2593 (15) keV level was previously observed in the  $^{125}\text{Te}(p, d)$  reaction of ref. <sup>20)</sup>.

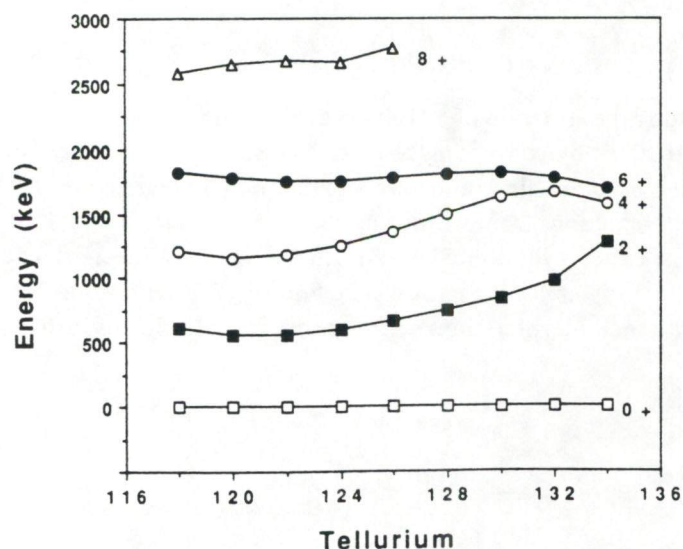


Fig. 4. Systematics of energy levels of yrast states in Te nuclei as a function of neutron number. Data are taken from ref. <sup>33)</sup>.



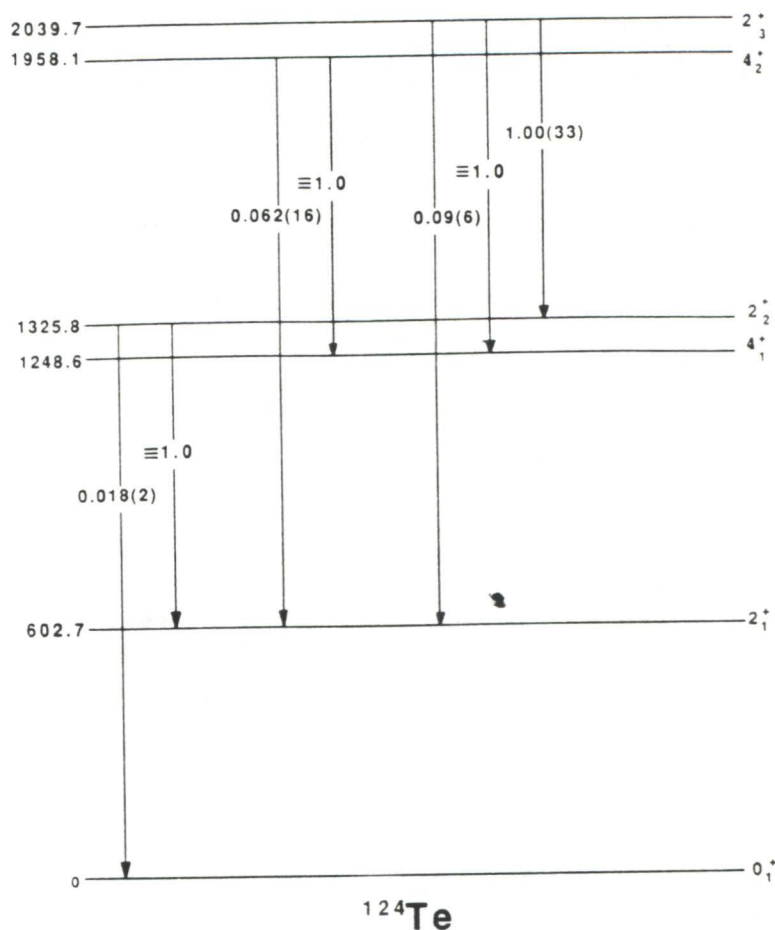


Fig. 5. Relative  $B(E2)$  branching ratios for low-lying excitations.

limiting case. The  $4_2^+$  state also resembles a normal collective state, without the signature of any anomalous collective structure, such as a 4p2h intruder state. Our ratio of  $(4_2^+ \rightarrow 2_1^+)/ (4_2^+ \rightarrow 4_1^+)$  is 18 times smaller than that predicted from the Alaga rule for the decay of the  $4^+$  member of a  $K^\pi = 0^+$  band. This normal behavior of the collective states does not support the existence of an important intruder component in excitations below 2 MeV, a conclusion which becomes even more apparent when compared with our results<sup>25)</sup> for  $^{122}\text{Te}$ .

However, a deviation from a pure harmonic vibrational structure is evident in the first two yrast states,  $2_1^+$  and  $4_1^+$ . While the energy ratio  $E(4_1^+)/E(2_1^+) = 2.07$  is close to the limiting value of 2.00, the  $B(E2)$  ratio<sup>26)</sup>  $B(E2; 4_1^+ \rightarrow 2_1^+)/B(E2; 2_1^+ \rightarrow 0_1^+) = 1.37(2)$  is quite different from 2.00. Furthermore, the empirical value<sup>26)</sup> of the electric quadrupole moment of the  $2_1^+$  state, 0.54 b, suggests that  $^{124}\text{Te}$  may be deformed. The DDM calculation<sup>5-7)</sup> shows that a potential minimum occurs at  $\beta \approx 0.2$ , independent of  $\gamma$  values, which would imply that  $^{124}\text{Te}$  is a better example

TABLE 4  
Relative  $B(E2)$  ratios for transitions depopulating low-lying states of <sup>124</sup>Te

| $\frac{B(E2; I_i - I_f)}{B(E2; I_i - I_k)}$ | Present work<br>( $\alpha, 2n$ ) <sup>b)</sup> | Other exp.           |                               |                                                      | IBA-1 limit <sup>a)</sup> |      | Theory                |                   |
|---------------------------------------------|------------------------------------------------|----------------------|-------------------------------|------------------------------------------------------|---------------------------|------|-----------------------|-------------------|
|                                             |                                                | Coulex <sup>c)</sup> | ( $n, \gamma$ ) <sup>d)</sup> | $\beta^-$ ( <sup>124</sup> Sb) <sup>e)</sup>         | SU(5)                     | O(6) | IBA-2 <sup>e,f)</sup> | DDM <sup>g)</sup> |
| $\frac{2_2^- - 0_1^-}{2_2^- - 2_1^-}$       | 0.018 (2) <sup>h)</sup>                        | 0.0077 <sup>i)</sup> | 0.0086 (4)                    | 0.0067 (2) <sup>j)</sup><br>0.0079 (6) <sup>l)</sup> | 0                         | 0    | 0.0069 <sup>k)</sup>  | 0.044             |
| $\frac{4_2^- - 2_1^-}{4_2^- - 4_1^-}$       | 0.062 (16) <sup>m)</sup>                       |                      | 1.25 (78)                     | 0.0067 (2) <sup>j)</sup><br>1.01 (4) <sup>l)</sup>   | 0                         | 0    | 0.002 <sup>n)</sup>   | 0.022             |
| $\frac{2_3^- - 2_2^-}{2_3^- - 4_1^-}$       | 1.00 (33) <sup>o)</sup>                        |                      | 0.4 (1)                       | 5.35 (34) <sup>p)</sup><br>3.5 (16) <sup>l)</sup>    | 0.56                      | -    | 0.25 <sup>q)</sup>    | 0.1               |
| $\frac{2_3^- - 2_1^-}{2_3^- - 4_1^-}$       | 0.09 (6) <sup>r)</sup>                         |                      | 0.13 (7)                      | 0.088 (5) <sup>p)</sup><br>0.06 (3) <sup>l)</sup>    | 0                         | -    | 0.036 <sup>s)</sup>   | 0.0017            |

<sup>a)</sup> From ref. <sup>21)</sup>.

<sup>b)</sup> The uncertainties are a combination of errors on the intensities and on the mixing ratios.

<sup>c)</sup> From ref. <sup>22)</sup>.

<sup>d)</sup> Results from the combined ( $n, \gamma$ ) and  $\beta^-$  (<sup>124</sup>Sb) measurements of ref. <sup>4)</sup>.

<sup>e)</sup> From ref. <sup>10)</sup>.

<sup>f)</sup> From ref. <sup>23)</sup>.

<sup>g)</sup> From ref. <sup>5)</sup>.

<sup>h)</sup> Used  $\delta = -3.3$  (2) of ref. <sup>24)</sup>.

<sup>i)</sup> Used experimental results of E2 matrix elements in ref. <sup>22)</sup>:  $\langle 0_1 | E2 | 2_2 \rangle = 0.110 e \cdot b$ ,  $\langle 2_1 | E2 | 2_2 \rangle = 1.253 e \cdot b$ .

<sup>j)</sup> From ref. <sup>2)</sup>.

<sup>k)</sup> IBA-2 calculation including an intruder configuration, taken from ref. <sup>10)</sup>.

<sup>l)</sup> From ref. <sup>3)</sup>.

<sup>m)</sup> Used  $\delta = +1.38$  (13) from internal conversion electron measurements of ref. <sup>6)</sup>.

<sup>n)</sup> From relative  $B(E2)$  values quoted in ref. <sup>10)</sup>.

<sup>o)</sup> Used  $\delta = +0.75$  (18) of ref. <sup>1)</sup>.

<sup>p)</sup> Note that the 2039.7 keV state is labelled as  $3^+$  instead of  $2^+$  in ref. <sup>2)</sup>.

<sup>q)</sup> Standard IBA-2 calculation of ref. <sup>23)</sup>.

<sup>r)</sup> Used  $\delta = +1.5$  (8) of ref. <sup>4)</sup>.

<sup>s)</sup> From relative  $B(E2)$  values quoted in ref. <sup>23)</sup>.

of a  $\gamma$ -unstable nucleus than <sup>196</sup>Pt. Relevant structure quantities predicted for <sup>124</sup>Te in the DDM agree well with those from an O(6) IBA-1 calculation. However, the decay of the  $2_3^+$  state is that expected of a vibrational three-phonon state and a  $\gamma$ -unstable nucleus with a substantial  $2_1^+$  electric quadrupole moment still remains to be understood. The data, therefore, do not support any simple collective description of <sup>124</sup>Te.

#### 4.2. SIGNATURE OF A MIXED-SYMMETRY STATE

The  $2_4^+$  state at  $E_x = 2091.6$  keV deexcites to the  $2_1^+$  state with a predominantly M1 transition,  $\delta(E2/M1) = 0.13(12)$ , as measured in ref. <sup>4)</sup>. This state cannot be understood in normal collective models. However, such a state arises naturally in a two-fluid model of collective motion, such as the IBA-2 or the work of Nojarov



and Faessler in ref. <sup>27</sup>). In the IBA-2 framework, where the differences in neutron and proton degrees of freedom are treated explicitly, excitations occur that are not fully symmetric under interchange of neutrons and protons. In vibrational or  $\gamma$ -unstable nuclei the lowest mixed-symmetry state <sup>28-30</sup>) is a  $2^+$  state, with favored M1 decay to the  $2_1^+$  state and enhanced E2 decay to the ground state. In a geometrical framework, out-of-phase (isovector) oscillations of neutrons and protons will give rise to  $2^+$  isovector quadrupole vibrations. The  $2_4^+$  state in  $^{124}\text{Te}$  has been previously proposed <sup>5,6,27</sup>) as such a mixed-symmetry or isovector excitation.

The group theoretical IBA-2 and geometrical model <sup>27</sup>) of Nojarov and Faessler give the same predictions for  $^{124}\text{Te}$ . In the calculation of an isovector quadrupole vibration in  $^{124}\text{Te}$ , the  $2_4^+ \rightarrow 2_1^+$  transition is predominantly M1. Using the results of ref. <sup>27</sup>), together with the relation

$$\delta(E2/M1) = 0.835 E_\gamma(\text{MeV}) \langle 2_1^+ | E2 | 2_4^+ \rangle / \langle 2_1^+ | M1 | 2_4^+ \rangle$$

the isovector vibration description predicts  $0.02 < \delta < 0.55$ , in good agreement with the experimental value <sup>4</sup>) of  $\delta = 0.13$  (12). The work of ref. <sup>27</sup>) also predicts that the  $B(E2; 0_1^+ \rightarrow 2_4^+)$  is comparable to the  $B(E2; 0_1^+ \rightarrow 2_1^+)$ , with empirical value <sup>22</sup>) of  $0.569$  (10)  $e^2 \text{ b}^2$ . The ratio of these  $B(E2)$  values

$$R = \frac{B(E2; 0_1^+ \rightarrow 2_1^+)}{B(E2; 0_1^+ \rightarrow 2_4^+)},$$

is then expected to be  $2 < R < 4$  for isovector quadrupole vibrations. In the IBA-2 framework for vibrational SU(5) nuclei, an expression for  $R$  has been obtained analytically <sup>29</sup>)

$$R = \frac{[e_\pi N_\pi + e_\nu N_\nu]^2}{(N_\pi N_\nu)(e_\nu - e_\pi)^2}.$$

For  $^{124}\text{Te}$ ,  $N_\pi = 1$  and  $N_\nu = 5$ ; using the best-fit value <sup>6</sup>) of the effective charges,  $e_\pi = 0.23$ ,  $e_\nu = 0.086$ , the SU(5) limit predicts  $R = 2.04$ , which is in good agreement with the geometrical expectations. An important test of these predictions would be a measure of the absolute  $0_1^+ \rightarrow 2_4^+$  transition rate.

#### 4.3. INTRUDER STATES AND TWO-STATE MIXING

The role of intruders and the type of collective motion in  $^{124}\text{Te}$  can be studied by examining the properties of the excited  $0^+$  states. While we did not populate any excited  $0^+$  states in the present study, four excited  $0^+$  states have been identified in previous work <sup>4</sup>), and are dotted in our level spectrum in fig. 3. The  $0_2^+$  state has been suggested as the band head of a 4p2h intruder band, or as the head of the  $\sigma < \sigma_{\text{max}}$  sequence in a  $\gamma$ -unstable or O(6) nucleus <sup>1,6,7</sup>), because the energy is elevated compared to the position of the other members of a possible two-phonon

triplet of a harmonic vibrator. The IBA-2 calculations which include mixing with an intruder configuration<sup>10)</sup>, predict well the properties of the  $0_2^+$  state in  $^{124}\text{Te}$ , in contrast to the DDM or standard IBA-2 calculations which are not as successful. However, the position of the second excited  $0_3^+$  state at 1883 keV has not been reproduced to within 200 keV by any calculation.

Conversion electron measurements provide a valuable means of testing whether or not the  $0_2^+$  and  $0_3^+$  states are anomalous collective states, by studying electric monopole transitions. Relative ratios of  $B(E0; 0_i^+ \rightarrow 0_1^+)$  to  $B(E2; 0_i^+ \rightarrow 2_k^+)$ , often abbreviated as  $X_{ilk}$ , were measured by Subber *et al.*<sup>6)</sup> and for  $i = 2(k = 1), 3(k = 2)$  they agree well with the DDM calculation that is analogous to the IBA O(6) limiting symmetry. An independent measurement done by Giannatiempo *et al.*<sup>13)</sup> resulted in essentially the same values of  $X_{ilk}$  for  $^{122}\text{Te}$  as for  $^{124}\text{Te}$ , implying that the two excited  $0^+$  states in both nuclei can be understood as normal collective states, without the need to invoke mixing with an intruder configuration.

The quasiband to the right of the g.s.b. in fig. 3 has been proposed as a deformed intruder band and illustrates a situation similar<sup>25)</sup> to that of  $^{122}\text{Te}$ . As in earlier studies<sup>31)</sup>, we too have not been able to observe any intraband transitions for the  $I \leq 8^+$  members of the quasiband. Although the lack of intraband transitions in the quasiband and the lack of an  $I(I+1)$  rotational energy spacing present difficulties in identifying the role of intruder configurations, one intraband transition,  $8_2^+ \rightarrow 6_2^+$ , provides a possible measure of intruder components in the  $8_2^+$  and  $6_2^+$  states.

We have extracted an upper limit on the intensity of a  $\sim 919$  keV  $8_2^+ \rightarrow 6_2^+$  transition by examining the sum of spectra gated on the  $(6_1^+ \rightarrow 4_1^+)$ ,  $(4_1^+ \rightarrow 2_1^+)$ , and  $(2_1^+ \rightarrow 0_1^+)$  transitions. By taking into account the  $E_5^5$  dependence of E2 transition probabilities, we have extracted

$$\frac{B(E2; 8_2^+ \rightarrow 6_2^+)}{B(E2; 8_2^+ \rightarrow 6_1^+)} < 6.$$

This number is considerably smaller than the values of 20–50 which usually characterize the enhancement of intraband to interband transition rates. Rather, the deexcitation of the  $8_2^+$  state indicates that the states of interest have similar character.

One possible source for this reduced ratio may come from mixing between the normal and intruder  $8^+$  states. However, the final energy separation between the two  $10^+$  states in fig. 3 is only 18 keV; thus for two-state mixing the mixing matrix element is at most 9 keV. This minute mixing contribution cannot account for the reduction of the  $B(E2)$  ratio. More typically, mixing matrix elements of  $\sim 100$  keV have been necessary to explain the mixing between intruder and normal configurations in this mass region<sup>32)</sup>. Either the mixing strength between normal and intruder configurations in  $^{124}\text{Te}$  exhibits a very strong dependence on spin, decreasing dramatically as the angular momentum increases [an opposite conclusion to the results of ref.<sup>10)</sup>], or intruders do not play a significant role in the near-yrast excitations.





essentially identical. This is a signature of the importance of valence two-quasineutron excitations, which will be predominantly of  $(\nu h_{11/2})^2$  character.

The energies of the  $3^-$  states in  $^{120}\text{Cd}$  and  $^{124}\text{Te}$  are lower in excitation than in the other isotones. These states are probably predominantly collective octupole vibrations, an argument supported by their strong population in Coulomb excitation studies<sup>40)</sup>. The  $I^\pi \geq 5^-$  negative-parity states of  $^{124}\text{Te}$  probably involve at least one  $1h_{11/2}$  neutron. As displayed in fig. 6, these levels are at similar energies in the adjacent isotone,  $^{126}\text{Xe}$ . The negative-parity states form  $\Delta I = 2$  bands<sup>37-39)</sup> in  $^{126}\text{Xe}$ ,  $^{128}\text{Ba}$  and  $^{130}\text{Ce}$ ; there are also  $\Delta I = 2$  bands built upon the  $10^+$  states. Given the limited knowledge of high-spin states in the stable  $^{124}\text{Te}$ , band structures built on the negative-parity or  $10^+$  states have not been established. However, since the  $10^+$  states at 3137.1 and 3154.9 keV in  $^{124}\text{Te}$  have very similar characteristics to those in  $^{126}\text{Xe}$ , it is likely that these states are of similar structure. In  $^{126}\text{Xe}$  it has been suggested<sup>37)</sup> that one  $10^+$  state is of  $(\pi h_{11/2})^2$  and the other one of  $(\nu h_{11/2})^2$  character. Unfortunately, it will be difficult to determine additional information on high-spin states in  $^{124}\text{Te}$ , because the heaviest ion available for studying this nucleus in-beam is  $^4\text{He}$ .

### 5. Conclusion

The present work has used the relatively non-selective  $(\alpha, 2n)$  reaction to identify new excitations in  $^{124}\text{Te}$ . We have identified new  $8^+$  and  $10^+$  states, near the previously established  $8^+$  and  $10^+$  states, have extended information on negative-parity states to  $J^\pi = 9^-$ , have identified non-yrast  $4^+$  and  $5^+$  states, as well as provided additional multipolarity and mixing-ratio information in this  $Z = 52$  nucleus.

The interplay between single-particle and collective motions gives rise to a very complicated structure in  $^{124}\text{Te}$ . No existing nuclear model is able to explain all of the observed spectroscopic details. While the low-lying, low-spin states appear to be of predominantly collective nature, no simple model is able to explain the electromagnetic properties of all of these levels. At higher excitations, we cannot support the proposed intruder states. Our search for intraband transitions among candidates of an intruder band indicated that the "intruder" states have character similar to that of the "normal" states, and that mixing between these configurations could not explain the observed  $\gamma$ -ray deexcitation. The present work showed the need to obtain additional information on relative and absolute transition probabilities. It also highlighted the similarity between  $^{122}\text{Te}$  and  $^{124}\text{Te}$ . It is hoped that our continuing systematic study of the even and odd mass Te isotopes will help to understand further the details of the interplay between single-particle and collective degrees of freedom in these transitional nuclei.

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Superdeformation in  $^{198,196}\text{Pb}$

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A weakly populated rotational band with energy spacings characteristic of superdeformation has been found in the reaction  $^{154}\text{Sm}(^{48}\text{Ca}, xn)$  at  $E(^{48}\text{Ca})=205$  MeV. This band has seven transitions with an average  $\gamma$ -ray energy spacing of approximately 42 keV. It is assigned to  $^{198}\text{Pb}$  on the basis of the excitation-function results. We also confirm the isotopic assignment of a previously reported superdeformed (SD) band in  $^{196}\text{Pb}$  via the cross bombardments  $^{176}\text{Yb}(^{26}\text{Mg}, xn)$  and  $^{176}\text{Yb}(^{24}\text{Mg}, xn)$ . Three SD bands have now been identified in the Pb isotopes with neutron numbers 112, 114, and 116.

Three-dimensional Hartree-Fock calculations of Bonche *et al.*<sup>1</sup> and Girod *et al.*<sup>2</sup> (who employed an effective two-body interaction with pairing), as well as a cranked Strutinsky calculation of Chasman,<sup>3</sup> all predict well-developed secondary minima in nuclear energy surfaces throughout the  $A \sim 194$  mass region, suggesting the presence of superdeformed (SD) nuclear shapes. These predictions have been verified experimentally in a number of Hg (Ref. 4), Tl (Refs. 5 and 6), and Pb (Refs. 7 and 8) nuclei. There are now approximately 25 SD bands observed in 12 nuclei in this region. These SD nuclei show similar moments of inertia, identical transition energies, and quantized alignment. Our experiments are motivated by the desire to understand these new phenomena associated with superdeformation. We report here results from our continuing experimental work in the Pb isotopes: (1) a new SD band in  $^{198}\text{Pb}$ , and (2) confirmation of a previous<sup>7</sup> tentative isotopic assignment for a SD band in  $^{196}\text{Pb}$ .

Experiments were carried out at the Lawrence Berkeley

Laboratory 88-Inch Cyclotron using HERA. HERA is an array of 20 Compton-suppressed Ge detectors together with a  $4\pi$ , 40-element bismuth germanate inner ball.  $^{198}\text{Pb}$  was populated via the  $^{154}\text{Sm}(^{48}\text{Ca}, 4n)$  reaction at two incident energies,  $E(^{48}\text{Ca})=205$  and 210 MeV. The  $^{154}\text{Sm}$  target was made of three stacked  $500 \mu\text{g}/\text{cm}^2$  foils.  $^{196}\text{Pb}$  was studied by bombarding a  $^{176}\text{Yb}$  target with two Mg isotopes:  $^{24}\text{Mg}$  at  $E(^{24}\text{Mg})=122$  MeV and  $^{26}\text{Mg}$  at  $E(^{26}\text{Mg})=135$  MeV. These energies were chosen to maximize the population of  $^{196}\text{Pb}$  via the  $4n$  and  $6n$  evaporation channels, respectively. The  $^{176}\text{Yb}$  target was composed of three stacked ( $450$ ,  $450$ , and  $700 \mu\text{g}/\text{cm}^2$ ) foils. Doubly-coincident (twofold) Ge events were recorded, along with sum energy ( $H$ ) and multiplicity ( $K$ ) information from the inner ball, if at least six inner-ball detectors were triggered. Coincidence events between three or more Ge detectors were always recorded (with  $H$  and  $K$  information). In the  $^{198}\text{Pb}$  study,  $\sim 280$  million coincidence events were stored at each energy. For the  $^{196}\text{Pb}$



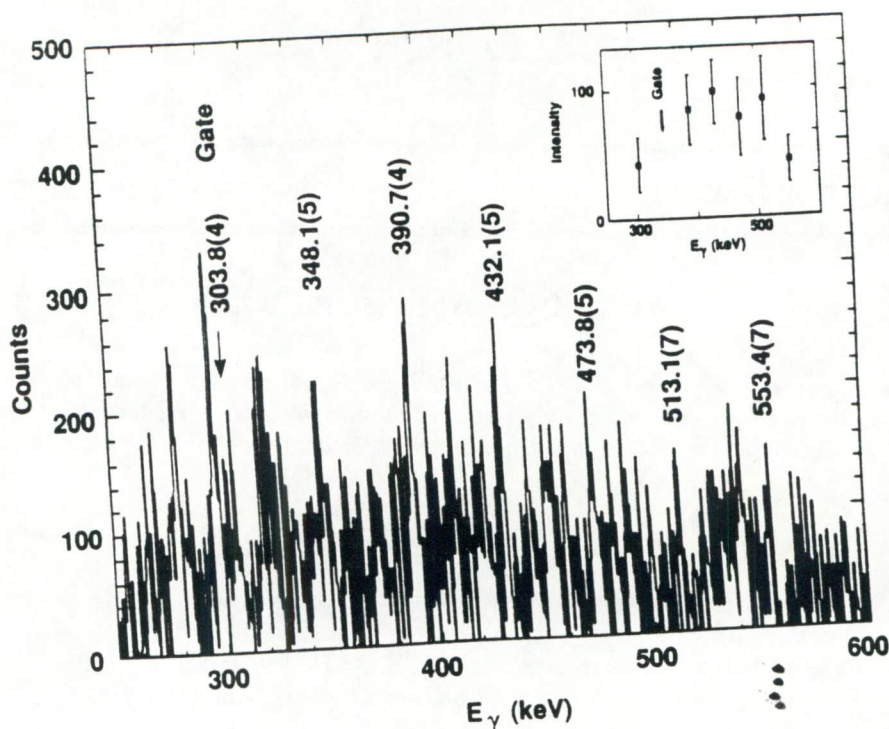


FIG. 1. Single-gated coincidence spectrum for the SD band in  $^{198}\text{Pb}$ ; transition energies with errors are shown. The intensity pattern of the SD band gated on the 348.1-keV transition is illustrated in the upper right corner.

study,  $\sim 130$  million and  $\sim 400$  million coincidences were stored at  $E(^{24}\text{Mg}) = 126$  MeV and  $E(^{26}\text{Mg}) = 135$  MeV, respectively. In each instance,  $\sim 80\%$  of the total recorded events were twofold coincidences.

Analysis of the  $^{198}\text{Pb}$  data was done with conditions  $H \geq 4.0$  MeV and  $K \geq 8$ . Figure 1 shows the energy spectrum and the intensity pattern of the SD band observed in the  $^{154}\text{Sm}(^{48}\text{Ca}, xn)$  reaction at  $E(^{48}\text{Ca}) = 205$  MeV. This band consists of seven transitions and is populated at  $\sim 1\%$  of the total  $^{198}\text{Pb}$  yield. The  $\gamma$ -ray energy difference between two adjacent transitions,  $\Delta E_\gamma$ , decreases gradually from  $\sim 44$  keV for the lowest-energy transitions to  $\sim 40$  keV at the highest-energy transitions. The change in  $\Delta E_\gamma$  per transition with increasing  $E_\gamma$  is the smallest among the SD bands so far found in Hg and Pb. The intensity ratios [the intensity obtained at  $E(^{48}\text{Ca}) = 205$  MeV to that at  $E(^{48}\text{Ca}) = 210$  MeV] of (i) the SD band, (ii) the high-spin states in  $^{198}\text{Pb}$ , and (iii) the high-spin states in  $^{197}\text{Pb}$  are summarized in Table I. There is no difference between the  $K \geq 8$  and  $K \geq 11$  results. The

number of events with  $K \geq 11$  is  $\sim 40\%$  of the number with  $K \geq 8$ . The SD band appears to have the same (within errors) excitation-function behavior as the high-spin states in  $^{198}\text{Pb}$ . We, therefore, assign this SD band to  $^{198}\text{Pb}$ . Coincidences between SD band members and transitions between known states below the  $12^+$  ( $\tau = 240$  ns) isomer<sup>9</sup> were not observed.

Figure 2(a) shows an 11-transition SD band observed in the  $^{176}\text{Yb}(^{26}\text{Mg}, xn)$  reaction at  $E(^{26}\text{Mg}) = 135$  MeV. Analysis was done with conditions  $H \geq 3.25$  MeV and  $K \geq 8$ . This band was previously found<sup>7</sup> in the  $^{176}\text{Yb}(^{24}\text{Mg}, xn)$  reaction at  $E(^{24}\text{Mg}) = 122$  MeV. Data from the latter reaction are shown in Fig. 2(b), along with the intensity pattern of the band.  $^{196}\text{Pb}$  is the only common nucleus populated in these two reactions and, therefore, we unambiguously assign this band to  $^{196}\text{Pb}$ . For this band  $\Delta E_\gamma$  decreases gradually from  $\sim 44$  to  $\sim 36$  keV as  $E_\gamma$  increases from 215 to 620 keV. No known low-lying transition between states below the  $12^+$  ( $\tau = 265$  ns) isomer<sup>10</sup> in  $^{196}\text{Pb}$  was found in coincidence with SD band members. No meaningful intensity pattern can be obtained from the data at  $E(^{26}\text{Mg}) = 135$  MeV. The spectral peaks of the SD band are more prominent in the spectrum obtained at  $E(^{24}\text{Mg}) = 122$  MeV than in the spectrum obtained at  $E(^{26}\text{Mg}) = 135$  MeV, although the intensity ratio of the 959-keV ( $14^+ \rightarrow 12^+$ ) transition<sup>10</sup> in  $^{196}\text{Pb}$  normalized to the total double-coincidence events at  $E(^{26}\text{Mg}) = 135$  MeV to that at  $E(^{24}\text{Mg}) = 122$  MeV is 0.86(2). This may be due to the population mechanism of the SD band or background produced by the other evaporation channels and fission at the higher incident energy.

The spin assignments of the members of these bands were obtained from least squares fits to the expression

TABLE I. The ratio of the intensity [normalized with respect to the corresponding total double-coincidence events; two different multiplicity conditions ( $K \geq 8$  and  $K \geq 11$ ) were selected] obtained at  $E(^{48}\text{Ca}) = 205$  MeV to the intensity at  $E(^{48}\text{Ca}) = 210$  MeV for (i) the SD band observed in the  $^{154}\text{Sm}(^{48}\text{Ca}, xn)$  reaction, and (ii) the high-spin states in  $^{198}\text{Pb}$ , and (iii) the high-spin states in  $^{197}\text{Pb}$ .

|                   | $K \geq 8$ | $K \geq 11$ |
|-------------------|------------|-------------|
| SD                | 2.5(9)     | 2.3(10)     |
| $^{198}\text{Pb}$ | 1.9(2)     | 1.8(2)      |
| $^{197}\text{Pb}$ | 0.8(1)     | 0.8(1)      |



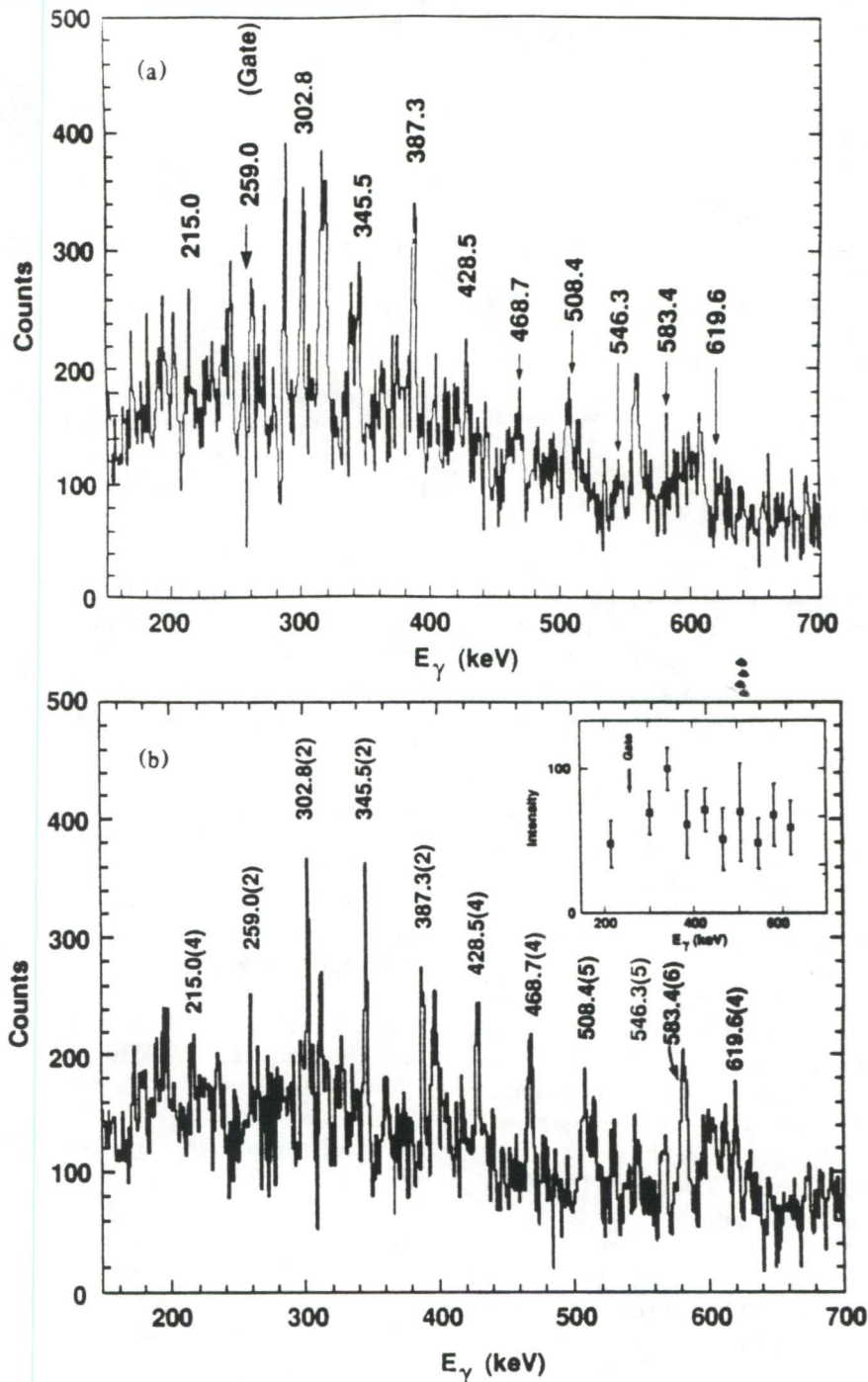


FIG. 2. (a) Spectrum for the  $^{196}\text{Pb}$  SD band (obtained from gating on the 259.0-keV  $\gamma$  ray) observed in the  $^{176}\text{Yb}(^{26}\text{Mg}, xn)$  reaction at  $E(^{26}\text{Mg}) = 135$  MeV. (b) The same band was found in the  $^{176}\text{Yb}(^{24}\text{Mg}, xn)$  reaction at  $E(^{24}\text{Mg}) = 122$  MeV; the spectrum was obtained from summing the 215.0-keV, 259.0-keV, and 508.4-keV gates. The intensity pattern obtained from the 259.0-keV gate is also shown.

( $\hbar = 1$ ):

$$I + \frac{1}{2} = 2a\omega + \frac{4}{3}\beta\omega^3. \quad (1)$$

With the choice  $\omega = dE/dI = E_f/2$ ,  $I$  is the intermediate spin in the transition  $I+1 \rightarrow I-1$  (see also Refs. 11 and 12). The  $^{198,196}\text{Pb}$  data do not have sufficient statistics for making directional correlation analysis, and we made a reasonable assumption that these cascade  $\gamma$  rays of the SD band have multipolarity  $L=2$ . There are three free parameters in the fit:  $I_f$  (the spin of the lowest band member) and the inertial parameters  $\alpha$  and  $\beta$ . All seven

transitions were used in the fit for  $^{198}\text{Pb}$ , and only the nine lowest-energy transitions were used for  $^{196}\text{Pb}$ . Results are summarized in Table II. The 303.8-keV  $\gamma$  ray in  $^{198}\text{Pb}$  is assigned as  $I_i \rightarrow I_f = 14 \rightarrow 12$ , and the 215-keV  $\gamma$  ray in  $^{196}\text{Pb}$  corresponds to an  $I_i \rightarrow I_f = 10 \rightarrow 8$  transition. In the  $^{198}\text{Pb}$  spin assignment, we use the fact that the level spin of an even-even nucleus is integer.

Figure 3 shows  $\mathcal{J}^{(2)}$ , the dynamic moment of inertia, for the SD bands in  $^{198}\text{Pb}$  and  $^{196}\text{Pb}$ , as a function of  $(\hbar\omega)^2$ . Lines through the data points are obtained with the parameters for integer values  $I_f$  in Table II. The  $\mathcal{J}^{(2)}$  values



TABLE II. Least-squares parameters from a fit of measured transition energies to  $I + \frac{1}{2} = 2a\omega + \frac{1}{2}\beta\omega^3$  (see text). The errors are statistical only, and when  $\chi^2/\nu < 1$ , the error represents the uncertainty:  $(\chi^2/\nu)^{1/2}\sigma$ . The second row for a given nucleus represents the fit done with a fixed integer value  $I_f$ .

| $^A Z$            | $E_\gamma$<br>(keV) | $\alpha$ ( $\times 10^{-2}$ )<br>(keV $^{-1}$ ) | $\beta$ ( $\times 10^{-8}$ )<br>(keV $^{-3}$ ) | $I_f$     |
|-------------------|---------------------|-------------------------------------------------|------------------------------------------------|-----------|
| $^{194}\text{Pb}$ | 169.7(2)            | 4.408(24)                                       | 8.17(43)                                       | 6.02(5)   |
|                   |                     | 4.398(4)                                        | 8.33(16)                                       | 6         |
| $^{196}\text{Pb}$ | 215.0(4)            | 4.344(20)                                       | 6.28(27)                                       | 7.94(5)   |
|                   |                     | 4.369(2)                                        | 5.95(11)                                       | 8         |
| $^{198}\text{Pb}$ | 303.8(4)            | 4.265(65)                                       | 5.87(74)                                       | 11.74(17) |
|                   |                     | 4.361(7)                                        | 4.83(21)                                       | 12        |

of the SD band<sup>7,8</sup> in  $^{194}\text{Pb}$  are included in Fig. 3 for comparison. While many of the even-even nuclei have similar  $\mathcal{J}^{(2)}$ , the  $\mathcal{J}^{(2)}(^{198}\text{Pb})$  and  $\mathcal{J}^{(2)}(^{196}\text{Pb})$  are different than  $\mathcal{J}^{(2)}(^{194}\text{Pb})$ , although all three nuclei have almost the same moment of inertia,  $2a$ . The change in  $\mathcal{J}^{(2)}$  per transition decreases with increasing neutron number. A possible interpretation is that the pairing does not change as much with frequency in  $^{198,196}\text{Pb}$  as in  $^{194}\text{Pb}$ . The alignment<sup>13</sup> of the  $^{198,196}\text{Pb}$  SD bands with increasing  $\hbar\omega$  does not saturate at a quantized value (i.e., integer or half-integer) with respect to the  $^{192}\text{Hg}$  (or  $^{193}\text{Tl}$ ) reference SD band (see Refs. 13 and 6 for the prescription and details), in contrast to the many other SD bands in this region. Furthermore, the SD bands in  $^{198,196}\text{Pb}$  do not show quantized alignment with respect to any reported SD band in the  $A = 194$  region.

An important result of this experiment is that the region of superdeformation is extended to  $N = 116$ . All calculations predict well-defined secondary minima in  $^{194}\text{Pb}$ ,  $^{196}\text{Pb}$ , and  $^{198}\text{Pb}$ ; however, the excitation energy of the second well increases with increasing neutron number. For example, Bonche *et al.*<sup>1</sup> predict that the depth of the second minimum increases from 1.73 MeV for  $^{194}\text{Pb}$  to 2.59 MeV for  $^{198}\text{Pb}$  while the excitation energy increases from 4.86 MeV to 8.28 MeV. The calculation of Chasman<sup>3</sup> includes angular momentum. He predicts that the second minimum in  $^{198}\text{Pb}$  at  $I = 40$  has depth  $\sim 3.4$  MeV and excitation energy  $\sim 4.2$  MeV above yrast. Based on Chasman's calculation, our observation of the SD band in  $^{198}\text{Pb}$  is surprising and suggests that the population mechanism is not yet well understood.

Bonche *et al.*<sup>14</sup> have discussed the termination of the SD cascade and the decay to the first well states. They made fully self-consistent generator coordinate method calculations on a basis of quadrupole constrained Hartree-Fock plus BCS wave functions. In-band *versus* out-of-band quadrupole decay was evaluated, and they find (i) the depopulation of the SD band takes place at approxi-

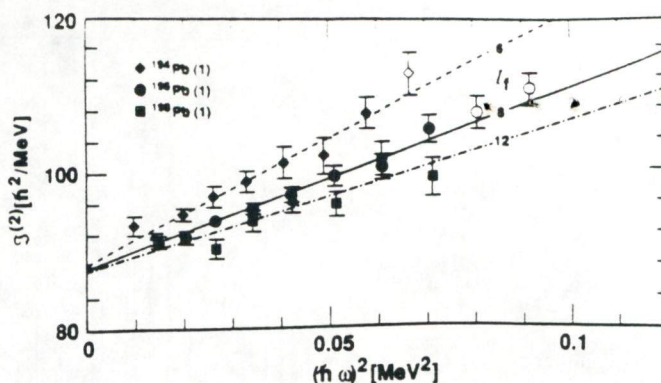


FIG. 3. The dynamic moment of inertia  $\mathcal{J}^{(2)}$  of the SD band in  $^{194}\text{Pb}$ ,  $^{196}\text{Pb}$ , and  $^{198}\text{Pb}$  as a function of  $(\hbar\omega)^2$ . The lines are calculated from the parameters  $\alpha$  and  $\beta$  obtained with integer values of  $I_f$ . The solid symbols indicate the transitions which were used in the fits.

mately the correct spin value in Hg and Pb and (ii) the decay of the SD band occurs in 1-2 transitions. Also, the predicted trend of the cascade termination with  $A$  is consistent with experimental results. They predict that the SD band depopulates at  $I = 12$  in  $^{198}\text{Pb}$ , as we observed in our experiment.

The behavior of the inertial parameter  $a$  with mass  $A$  is interesting (see Table II):  $a$  is constant within 1% as  $A$  changes from 194 to 198, while the rigid body moment of inertia ( $\propto A^{5/3}$ ) would give a 3% change. Krieger *et al.*<sup>15</sup> have calculated the moment of inertia and the electric quadrupole moment for the even-even Pb isotopes with  $A$  between 190 and 218. The predicted moment of inertia show a 3% increase between  $A = 194$  and 198, and a flat plateau which changes  $\sim 1.5\%$  (per four mass units) in the mass region  $A = 198-210$ .

In summary, we have extended the region of superdeformation to  $N = 116$ .  $^{198}\text{Pb}$  is the heaviest nucleus in this mass region where the superdeformation is known. Further experiments, e.g., a search for SD bands in heavier Pb nuclei ( $^{199,200}\text{Pb}$ ) and lighter Pb nuclei ( $^{191,192}\text{Pb}$ ), as well as finding linking transitions are essential to understanding the physics associated with superdeformation.

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## ENERGY RATIOS IN MEDIUM AND HEAVY MASS NUCLEI. SIGNATURES OF COEXISTING CONFIGURATIONS

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Energy ratios of low-lying  $2^+$ ,  $4^+$  and  $6^+$  states are examined for several regions of the periodic table. A linear function of  $R(4/2)$  characterizes  $R(6/4)$  for nearly all collective nuclei with  $A > 60$ . Deviations from this smooth systematic behavior provide a signature of coexisting collective and non-collective configurations in the yrast excitations.

Structure in nuclei near closed shells at low excitations is dominated by the excitation of a few valence particles into spherical shell model orbitals. Away from shell closure, this structure is dominated by quadrupole collective excitations: vibrations near the shell closure, rotations in mid-shell. Our understanding of these low-lying excitations, however, is frequently complicated by coexisting shapes or intruder configurations. It would be useful to identify a clear signature for these coexisting structures which alter the low-lying level spectra. Such a signature could possibly point to a unified origin of the source for these intruders.

In the present work we examine the energy ratios

$$R(4/2) = E(4_1^+)/E(2_1^+),$$

$$R(6/4) = E(6_1^+)/E(4_1^+),$$

and will note how  $R(6/4)$  varies as a function of  $R(4/2)$  for various regions of even-even nuclei with  $A > 60$ . Several previous studies [1-4] have investigated energy ratios, but mostly based on the classic work of Mallmann [1], in which energy ratios with respect to the  $2_1^+$  state alone were considered. Mallmann was also the first to note nearly universal energy ratio systematics for nuclei across the periodic table. We shall examine, how  $R(6/4)$ , rather than Mallmann's  $R(6/2)$ , signals irregular behavior, and contrast the systematic behavior of this ratio to energy ratios and predictions considered in earlier works.

To interpret these energy ratios we shall make use of the simplest geometrical models and their predictions. For a harmonic vibrator the excitation energies obey the expression

$$E = \alpha n_d,$$

where  $n_d$  is a phonon number:  $n_d=0$  for the ground state,  $n_d=1$  for the  $2_1^+$  state,  $n_d=2$  for the  $4_1^+$  state,  $n_d=3$  for the  $6_1^+$  state, etc. For an axial rotor, the yrast excitation energies are given by

$$E = \alpha[J(J+1)]$$

for  $J=0, 2, 4, 6, \dots$ , for the ground-state band. For a gamma-unstable rotor

$$E = \alpha[\tau(\tau+3)],$$

where  $\tau$  is similar to a phonon number:  $\tau=0, 1, 2, 3, \dots$  for the ground,  $2^+$ ,  $4^+$ ,  $6^+$ , ... yrast states, respectively. Therefore, one expects  $R(4/2)=2.0$ ,  $R(6/4)=1.5$  for a harmonic vibrator;  $R(4/2)=3.33$ ,  $R(6/4)=2.10$  for an axial rotor; and intermediate values for non-axial shapes. In contrast, for nuclei with few valence particles the energy ratios are quite different, frequently characteristic of coupling via a delta interaction two single particles with angular momentum  $j$  to  $J$ . For example, in  $^{210}\text{Po}$   $R(4/2)=1.21$  and  $R(6/4)=1.03$ .

We shall define the onset of quadrupole collective motion when  $R(4/2)=2.0$ , which implies in the simplest picture that  $R(6/4)=1.5$ . When we plot the  $R(6/4)$  values as a function of  $R(4/2)$ , the space is

divided into four regions, as illustrated in fig. 1. Region 1, nuclei with  $R(4/2) < 2.0$  and  $R(6/4) < 1.5$ , shall be characterized as representative of single-particle excitations; we place no expectations on how the energy ratios should be related to each other. Region 2, nuclei with  $R(4/2) \geq 2.0$  and  $R(6/4) \geq 1.5$ , shall be characterized as representative of collective excitations. This procedure leaves two "forbidden" regions, for which  $R(4/2) > 2.0$  but  $R(6/4) < 1.5$ , and  $R(4/2) < 2.0$  but  $R(6/4) > 1.5$ . Identifying nuclei in these regions could indicate intruder configurations since the ratios representative of collective motion are not consistent for the yrast excitations.

In fig. 2 we display the behavior of  $R(6/4)$  as a function of  $R(4/2)$  for three regions of the periodic table. To simplify our presentation we have chosen a doubly-magic nucleus, and then plot the energy ratios for all nuclei with neutron numbers from the closed shell up to and including mid-shell. In fig. 2 are displayed the systematics for two different sets of elements near  $^{146}\text{Gd}$  and the systematics for nuclei above  $^{208}\text{Pb}$ . First, the nuclei displayed were not pre-selected, except by their  $N$  and  $Z$  values, with the data for the most part taken from the most recent compilation of Sakai [5]. Second, these systematics illustrate that, as expected, essentially no nuclei have energy ratios that fall into the "forbidden" regions. These nuclei can then be characterized as well-behaved with no evidence of coexisting structures: the

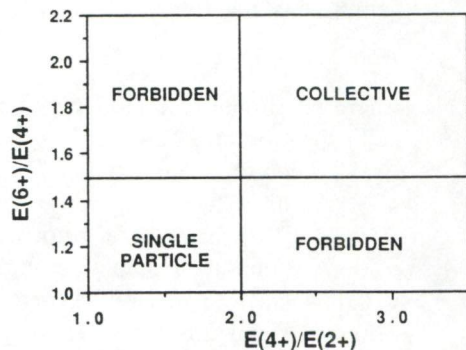


Fig. 1. Schematic figure of  $R(6/4)$  values as a function of  $R(4/2)$ . Region 1 with  $R(4/2) < 2.0$  and  $R(6/4) < 1.5$  represents values characteristic of single-particle excitations. Region 2 with  $R(4/2) \geq 2.0$  and  $R(6/4) \geq 1.5$  represents values characteristic of collective excitations. The regions labeled "forbidden" represent values which do not indicate a consistent structure for the yrast excitations.

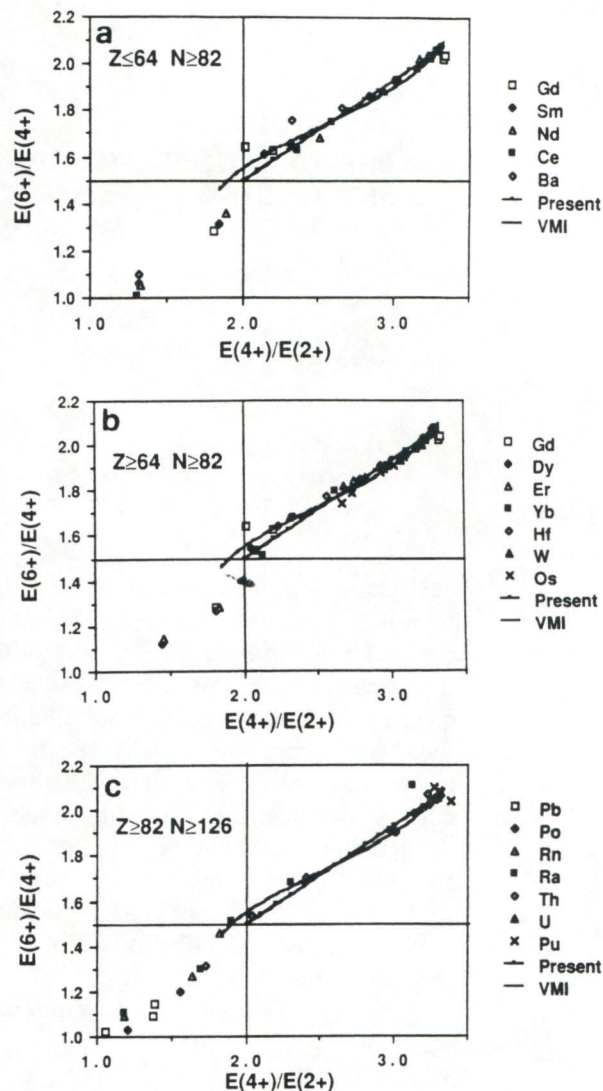


Fig. 2.  $R(6/4)$  values as a function of  $R(4/2)$  values for nuclei with (a)  $Z \leq 64$ ,  $N \geq 82$ ; (b)  $Z \geq 64$ ,  $N \geq 82$ ; and (c)  $Z \geq 82$ ,  $N \geq 126$ . The "present" predictions are from eq. (1) as discussed in the text; the VMI prediction uses the  $\alpha$  root in transitional nuclei. The data are taken from refs. [5-16].

nuclei are either collective or single-particle in nature. Also, there is a linear relationship between  $R(6/4)$  and  $R(4/2)$  and this relationship is the same for these rather different sets of nuclei, spanning elements from Ba to Pu. From the line through the data of fig. 2 we obtain:

$$R(6/4) = a R(4/2) + b, \quad (1)$$

where  $a = 0.433$  and  $b = 0.633$ . This allows a predic-



tion of the  $6^+$  energies for all collective shapes, not only harmonic vibrators and deformed rotors, given the energies of the lowest  $2^+$  and  $4^+$  states.

The most successful attempt to understand universal energy systematics in all regions of the periodic table is the variable moment of inertia (VMI) model [2] of Mariscotti, Scharff-Goldhaber, and Buck. Originally this model was limited to nuclei with  $2.23 < R(4/2) \leq 3.33$ , but was later extended [3,4] to nuclei with  $1.82 < R(4/2) < 2.23$ , by allowing for negative moments of inertia in "spherical" nuclei. In this model the energy of the level with angular momentum  $J$  is given by [2]

$$E(J) = \frac{1}{2}C[\Theta(J) - \Theta(0)]^2 + \frac{1}{2}[J(J+1)/\Theta(J)], \quad (2)$$

and the equilibrium condition

$$\partial E(J)/\partial \Theta(J) = 0,$$

where  $\Theta(J)$  is the moment of inertia of the state with angular momentum  $J$ , and  $C$  is related to the softness parameter  $\sigma$  by

$$\sigma \equiv \frac{1}{2}C\Theta(0)^2. \quad (3)$$

The yrast excitation energies are real solutions of a cubic equation, which can be written as [3]

$$e^3 - 2e^2 + (1 + 36d)e - 4(1 + 27d)d = 0, \quad (4)$$

where  $e = E_r(J)/[\Theta(0)^2/8C]$  and  $d = [C/\Theta(0)^3] \times J(J+1)$ . For  $1.82 < R(4/2) < 2.23$  three real roots for eq. (4) are obtained, but only one, the  $\alpha$  root of ref. [3], is physical for all values of angular momentum. (Alternative yrast sequences, the  $\alpha$ - $\gamma$  and  $\alpha$ - $\beta$ - $\gamma$  roots, have been obtained [3] by combining real solutions with the requirement that the energy increases as a function of angular momentum. In the figures we have used the  $\alpha$  root in our comparisons.) In examining energy ratios there is no dependence on the parameters  $\Theta(0)$  and  $C$ .

The VMI predictions for energy ratios were able to reproduce well [2-4] the systematics of energy ratios to the  $2^+$  states, e.g.,  $R(6/2)$  versus  $R(4/2)$ ,  $R(8/2)$  versus  $R(4/2)$ . A comparison of the linear expression obtained in the present work and the VMI predictions is presented in fig. 2. The present empirical linear fit and the VMI predictions reproduce the data with comparable quality. However, the VMI predictions are not linear, and the empirical linear fit

may be better for nuclei transitional between vibrational and non-axial shapes. The VMI model is motivated by an expected change in the moment of inertia as the nucleus rotates and therefore, does have a physical justification, lacking in our present empirical linear fit. However, the physical justification of negative moments of inertia, necessary to consider transitional nuclei in the VMI, is not fully understood.

In fig. 3a we examine another set of nuclei near  $^{146}\text{Gd}$ , with  $Z \leq 64$  and  $N \leq 82$ . There is a marked contrast between these systematics and those presented in fig. 2: many nuclei (isotopes of Te and several  $N=80$  nuclei) have energy ratios that fall in the "forbidden" regions of the figure. These deviations are more clearly evident in fig. 3a than in traditional plots of  $R(6/2)$  versus  $R(4/2)$ , illustrated in fig. 3b. The present empirical fit, derived from eq. (1) with the present parameters, provides essentially identical agreement with the data in fig. 3b as the VMI model predictions. That the data in fig. 3a are somewhat better reproduced by the linear fit, than the VMI predictions, is not understood. The ratio  $R(6/4)$ , however, is independent of VMI trajectory for the transitional region, which may make it a less model dependent variable than  $R(6/2)$ .

For the  $N=80$  nuclei, the  $R(4/2)$  values displayed in fig. 3a are greater than 2.0, which would indicate a collective, possibly non-axial, structure, while the  $R(6/4)$  values are representative of non-collective structure. In the  $N=80$  nuclei a low-lying  $6^+$  state can only be made from  $(\pi g_{7/2})^2$  or  $(\pi g_{7/2}d_{5/2})$  valence configurations, while there are many ways to construct  $2^+$  states from the valence neutron and proton orbitals. The  $6^+$  state is then predominantly a two-quasiproton excitation, the  $2^+$  state is collective, and relatively low in energy, and the  $4^+$  state is at best moderately collective. The large  $R(4/2)$  value then comes from the lowering of the  $2^+$  state because of its collective nature, while the  $4^+$  and  $6^+$  states remain rather high in excitation. The  $R(4/2)$  value is, therefore, not a signature of non-axial structure, but rather reflects coexistence of collective and single-particle excitations in the yrast states. A similar deviation from the simple systematic occurs in the  $A=80$  region for nuclei with  $N=48$ . This trend may signal a general feature of nuclei with two neutron holes: while the  $2_1^+$  state is collective because it is relatively easy to configure low-lying  $2^+$  excitations, the



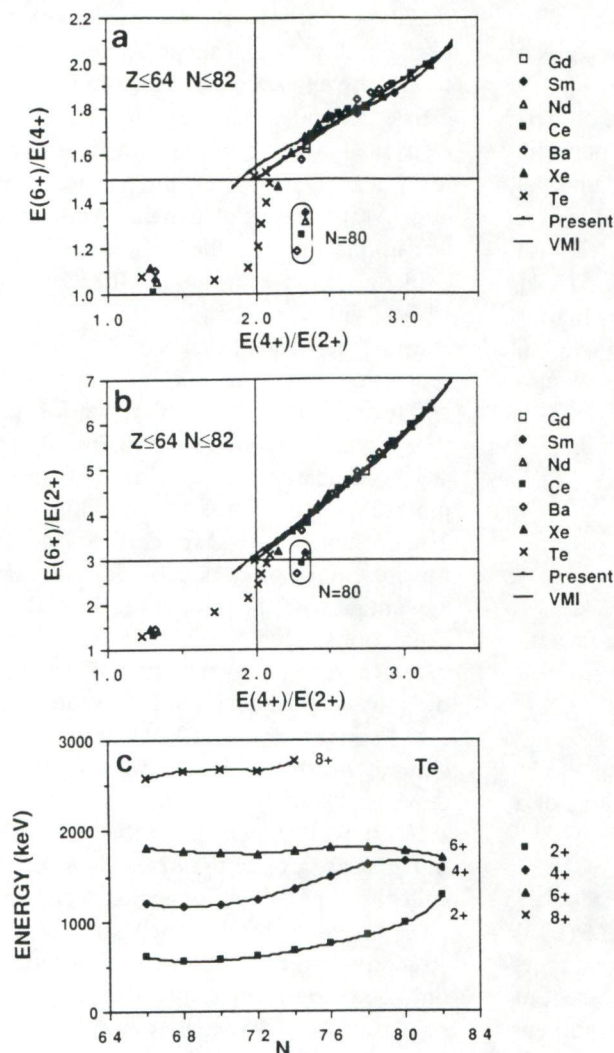


Fig. 3. (a)  $R(6/4)$  values as a function of  $R(4/2)$  for nuclei with  $Z \leq 64$  and  $N \leq 82$ . (b)  $R(6/2)$  values as a function of  $R(4/2)$  for nuclei with  $Z \leq 64$  and  $N \leq 82$ . The "present" results are derived from eq. (1) with the parameters discussed in the text and are essentially identical to the VMI predictions. (c) Energy level systematics as a function of neutron number  $N$  for Te nuclei. The data are taken from refs. [5,17-19].

higher members of the yrast band are predominantly two-quasiproton excitations, and caution should be used in applying a single collective description to these nuclei. It would be important to obtain additional information on  $N=124$  nuclei to see if this pattern is a universal feature.

The other nuclei in fig. 3a which show marked deviations from the expected smooth systematical be-

havior are the Te isotopes with  $N=70-76$ . The  $R(4/2)$  values alone could signal non-axial shapes, which are expected from several calculations, including those by Kumar and coworkers using the dynamic deformation model [20]. However, the  $6_1^+$  state is predominantly a two-quasiproton excitation, a conclusion also supported in fig. 3c by the essentially constant energy of this state as a function of neutron number. Since the yrast energy ratios are affected by this coexistence of single-particle and collective excitations, a spherical vibrator description may be more appropriate for these nuclei.

In conclusion, we have examined the systematics of energy ratios of low-lying  $2^+$ ,  $4^+$ , and  $6^+$  states in nuclei with  $A > 60$ . A simple linear relationship between  $R(6/4)$  and  $R(4/2)$  values characterizes all collective nuclei, regardless of shape. By examining the  $R(6/4)$  values as a function of  $R(4/2)$  values we have found a simple signature of coexistence between single-particle and collective excitations along the yrast line, and have noted that this coexistence may routinely occur in nuclei with two neutron holes. The present work shows that care should be taken in using only  $R(4/2)$  values as an indication of the collective shape, since frequently this value is affected by coexisting structures.

We would like to thank Dr. A.J. Kreiner, Dr. R.F. Casten, Dr. P.D. Cottle, Dr. N. Benczer-Koller and Dr. J.P. Vary for critical discussions.

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# Identification of Higher Representations of the $U(6/4)$ Supersymmetry in the Nucleus $^{195}\text{Ir}$

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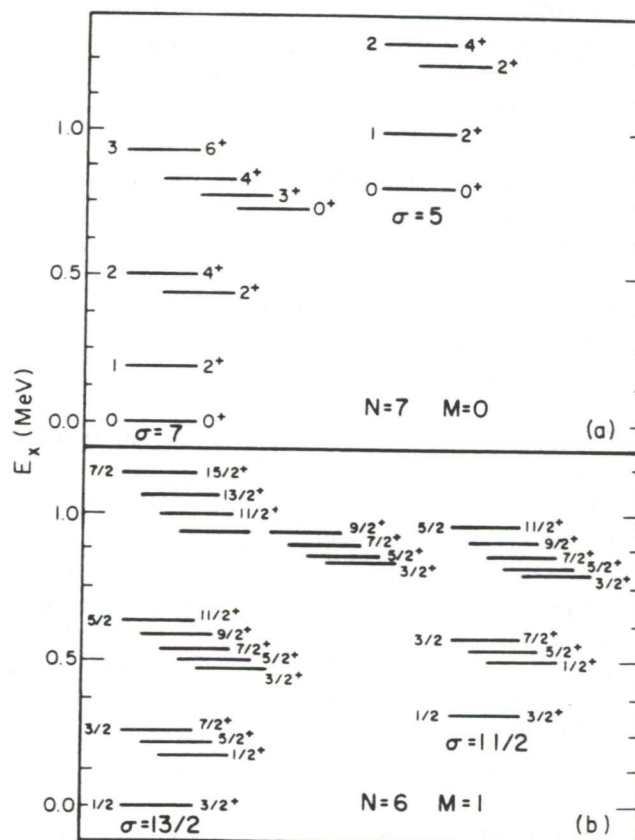
On the basis of recent  $^{193}\text{Ir}(2n, \gamma)^{195}\text{Ir}$  reaction measurements, we have identified new low-spin positive-parity states and their electromagnetic deexcitations in  $^{195}\text{Ir}$ . All of the low-lying states can be classified as those expected in a nucleus with a  $U(6/4)$  supersymmetry within the framework of the interacting boson-fermion approximation model. In particular, the spacings of the lowest levels (with  $\sigma = \sigma_{\text{max}} = \frac{11}{2}$ ) are repeated for another sequence, suggesting  $\sigma = \frac{11}{2}$  and, in consequence, the applicability of a supersymmetry description to  $^{195}\text{Ir}$ .

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One of the distinguishing characteristics of the  $O(6)$  or  $\gamma$ -unstable rotor limit<sup>1</sup> of the interacting-boson-approximation model (IBA) is the classification of levels in terms of the quantum numbers  $\sigma$  and  $\tau$ . In Fig. 1(a) we show a schematic diagram of the levels expected in an  $O(6)$  nucleus. The  $\tau$  quantum number is similar to a quadrupole phonon number. The  $\sigma$  quantum number is similar to a boson seniority quantum number and takes on its maximum value in the ground state. The  $0^+$  member of the two-phonon triplet of a vibrator is "missing," having been pushed up in energy by the repulsive pairing interaction that is the important boson-boson interaction in the  $O(6)$  limit. This  $0^+$  state is the head of the  $\sigma_{\text{max}} - 2$  sequence of levels.  $E2$  selection rules allow transitions with  $\Delta\tau = \pm 1$ ,  $\Delta\sigma = 0$ . A signature of the  $O(6)$  limit is a series of  $0^+ - 2^+ - 2^+$  levels with similar energy spacings and with strong  $E2$  transitions within each sequence, with relatively weak transitions between sequences. The  $\sigma < \sigma_{\text{max}}$  states are the characteristic structure that distinguishes the  $O(6)$  symmetry from other shapes, such as the anharmonic vibrator. This structure and several  $\sigma < \sigma_{\text{max}}$  states have been observed<sup>2</sup> in  $^{196}\text{Pt}$  and provided the initial identification of the  $O(6)$  limit of the IBA.

More recently there has been considerable interest in the supersymmetries and spinor symmetries that arise in the interacting-boson-fermion-approximation model (IBFA). Many of the candidates for nuclei exhibiting the supersymmetry structure have been found near regions of the periodic table containing nuclei that exhibit  $O(6)$  symmetry.<sup>3</sup> The initial example of a supersymmetry,<sup>4,5</sup> the  $U(6/4) \supset \text{Spin}(6)$  supersymmetry, where a  $j = \frac{3}{2}$  fermion couples to an  $O(6)$  boson core, was proposed for the Ir odd-mass nuclei with  $\frac{3}{2}^+$  ground states.  $^{191,193}\text{Ir}$  have been extensively studied and their level spacings,  $\gamma$ -ray

deexcitation, and single-particle transfer strengths are well reproduced by this symmetry.<sup>5,6</sup> However, few  $\sigma < \sigma_{\text{max}}$  states have been identified in these nuclei, so that the most definitive tests of the  $O(6)$  symmetries have been limited.





A schematic level scheme for an odd-mass nucleus exhibiting the  $U(6/4) \supset \text{Spin}(6)$  symmetry structure is shown in Fig. 1(b). The structure might suggest a weak coupling of a  $j = \frac{3}{2}$  fermion, but there are important differences. The expected  $\frac{3}{2}$  member of the  $\frac{1}{2} \times 2_1^+$  multiplet is "missing," having been pushed up in energy by the quadrupole interaction between the boson core and valence fermion. This state starts the sequence of levels with  $\sigma = \sigma_{\max} - 1$ , where  $\sigma_{\max} = N + \frac{1}{2}$  and  $N$  is the boson number. Built on this  $\sigma = \sigma_{\max} - 1$ ,  $\frac{3}{2}$  state is a sequence of levels, all with  $\sigma < \sigma_{\max}$ , that are a repetition of the low-lying level spacings. The identification of this plethora of levels would provide a definitive signature of  $U(6/4) \supset \text{Spin}(6)$  symmetry. The purpose of this Letter is to present the results of our recent measurements of excitations in  $^{195}\text{Ir}$  and demonstrate how the level spectrum manifests this boson-fermion symmetry via the identification of a complete sequence of  $\sigma = \sigma_{\max}$  levels.

In the present work, the electromagnetic deexcitation of levels in the neutron-rich nucleus  $^{195}\text{Ir}$  was studied following multiple neutron capture by enriched  $^{193}\text{Ir}$  targets at the High Flux Reactor of the Institut Laue Langevin. Gamma rays and conversion electrons following multiple neutron capture, both in saturation for the intermediate  $^{194}\text{Ir}$  nucleus and as a function of time, were measured with the high-resolution, high-sensitivity GAMS1, GAMS2/3 bent-crystal spectrometers and BILL electron spectrometer. Primary transitions to low-lying levels in  $^{195}\text{Ir}$  were measured with a pair spectrometer. The identification of transitions in  $^{195}\text{Ir}$  was aided by previous measurements of Raemy *et al.* of the  $^{193}\text{Ir}(n, \gamma)$  reaction<sup>7</sup> and the well-studied  $\beta$  decay<sup>8</sup> of  $^{194}\text{Ir} \rightarrow ^{194}\text{Pt}$ . The present study of electromagnetic transitions in  $^{195}\text{Ir}$  was only possible because of the high neutron flux  $[(3-5.5) \times 10^{14} \text{ neutrons/cm}^2 \text{ s}]$  at the target positions. The deduced neutron-capture cross section for the reaction  $^{194}\text{Ir}(n, \gamma)^{195}\text{Ir}$  is  $1500 \pm 300 \text{ b}$ . Further details of these measurements and the construction of the level scheme are discussed in Colvin *et al.*<sup>9</sup>

Prior to the current measurement the only information on excited states in  $^{195}\text{Ir}$  came from the studies of the reaction  $^{196}\text{Pt}(t_{\text{pol}}, \alpha)^{195}\text{Ir}^0$  which also established the  $J^\pi = \frac{3}{2}^+$  value for the ground state. The level spectrum shown in Fig. 2(a) was constructed by our combining the results from Ref. 6 and from the present neutron-capture measurements. New levels were determined from primary transitions. New spin-parity assignments were made by combination of previous measurements with multipolarities of transitions determined from the conversion electron measurements and placed with the Ritz combination method, which is valid given the high accuracy ( $\approx 2 \text{ eV}$  for many transitions) of the  $\gamma$ -ray energies.

In a supersymmetry the adjacent even- and odd-mass nuclei are members of the same supermultiplet characterized by  $\tilde{N} = N + M$ , where  $N$  is the usual boson number, and  $M$  is the number of fermions. Energy levels, for ex-

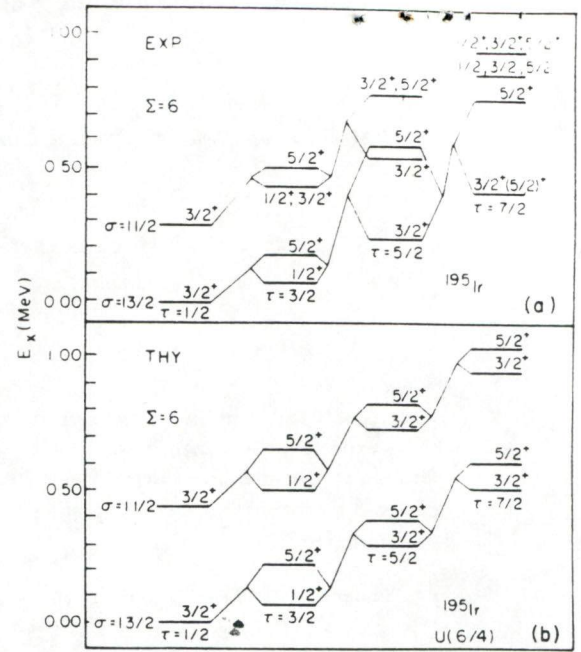


FIG. 2. Comparison between supersymmetry predictions and positive-parity states in  $^{195}\text{Ir}$ . The levels are labeled by  $\sigma$  and  $\tau$  quantum numbers of the  $U(6/4) \supset \text{Spin}(6)$  symmetry. The energy parameters are essentially those for  $^{194}\text{Os}$  obtained in Ref. 10.

ample, for the even- and odd-mass members of a supermultiplet can be predicted with the same set of parameters. For  $^{195}\text{Ir}$ , its supersymmetric partner is  $^{194}\text{Os}$ , a nucleus close to the  $O(6)$  limit of the IBA. The energy levels of  $^{194}\text{Os}$  were fitted previously.<sup>10</sup> Figure 2 shows the proposed assignment of  $U(6/4)$  quantum numbers to empirical levels in  $^{195}\text{Ir}$  and a comparison with the level structure predicted with the  $^{194}\text{Os}$  level parameters of Ref. 10. (The parameter  $A = 150 \text{ keV} = A_1 + A_2$  was taken from the fits to Os nuclei;  $A_2 = 100 \text{ keV}$  was the same value used to fit  $^{193}\text{Ir}$  levels in Ref. 6.) The correspondence between the predicted and empirical levels is based on all available spectroscopic information on states in  $^{195}\text{Ir}$  and is discussed in more detail in Ref. 9.

The correspondence between theory and experiment for many of the levels in  $^{195}\text{Ir}$  was based on energy orderings. However, the assignment of  $\text{Spin}(6)$  quantum numbers to the excited  $\frac{3}{2}^+$  states at about 250 keV was not straightforward because both of these states were populated fairly strongly in the earlier single-particle transfer study, while in the supersymmetry only one of these states (from the  $\sigma = \frac{11}{2}$  sequence) would be expected to be strongly populated. The present assignment of quantum numbers is based on the observed  $E2$  deexcitation, which in this supersymmetry scheme is expected to follow the  $\Delta\tau = 0, \pm 1$  selection rules. The 233-keV  $(\frac{13}{2}, \frac{5}{2})^+$  state is proposed as the  $(\sigma, \tau) = (\frac{13}{2}, \frac{5}{2})$  state because it decays preferentially to the  $(\frac{11}{2})^+$  state with an experimental ratio

$$\frac{B(E2: \frac{13}{2}^+ \rightarrow (\frac{11}{2})^+ (\frac{13}{2}, \frac{5}{2}))}{B(E2: \frac{13}{2}^+ \rightarrow (\frac{11}{2})^+ (\frac{13}{2}, \frac{3}{2}))} = \frac{4}{100}.$$



The 286-keV  $\frac{11}{2}^-$  state is then proposed as the  $\tau = \frac{1}{2}$  head of the  $\sigma = \frac{11}{2}$  sequence. It is this latter state which does receive<sup>6</sup> somewhat more of the excited  $d_{3/2}$  strength. Because the multipolarity of the ground-state transition is  $M1(+E2)$  and the multipolarities of the deexcitations to the  $(\frac{1}{2})_1^+$  and  $(\frac{3}{2})_1^+$  states have not been established, the  $\gamma$ -ray deexcitation of this state cannot be used to further support this assignment. However, the energy of this state, the single-particle transfer results, and the preferred  $\tau = \frac{5}{2}$  assignment for the 233-keV state, the only other possible candidate for the  $(\sigma, \tau) = (\frac{11}{2}, \frac{1}{2})$  state, all support the  $\sigma = \frac{11}{2}$  assignment for the 286-keV  $\frac{11}{2}^+$  level. The 428-keV  $\frac{1}{2}^+, \frac{3}{2}^+$  level is proposed as the  $J = \frac{1}{2}, \tau = \frac{3}{2}$  level; its deexcitations to the  $(\frac{3}{2})_1^+$  and  $(\frac{1}{2})_1^+$  states are  $M1(+E2)$ . This assignments to other members of the  $\sigma = \frac{11}{2}$  sequence are suggested by observed transitions to the first two candidates of this group of levels, transitions which would otherwise have been forbidden by the  $\Delta\sigma = 0$  selection rule. The next  $\sigma = \frac{9}{2}$  levels are predicted to be above 1 MeV in excitation; no definitive assignment can be made.

The most important result of this study is the identification of many members of the  $\sigma < \sigma_{\max}$  sequence of levels and the repetition of energy spacings of the lowest  $\sigma$  sequence in this higher sequence. All  $\frac{1}{2} \leq J \leq \frac{5}{2}$  states with  $\tau = \frac{1}{2}, \frac{3}{2}, \frac{5}{2}$ , and possibly  $\frac{7}{2}$  for both the  $\sigma = \frac{13}{2}$  and  $\sigma = \frac{11}{2}$  sequences have been identified, which are all of the low-lying low-spin levels expected given the energy parameters of Ref. 10. The repetition of energy spacings observed experimentally in the  $\sigma = \sigma_{\max}$  sequence for levels in the  $\sigma < \sigma_{\max}$  sequence is especially remarkable because the energy agreement between IBA or IBFA predicted and experimental levels is usually not outstanding, as is also evident in Fig. 2.

The excellent agreement between theory and experiment observed for  $^{195}\text{Ir}$  is upheld when the supersymmetry is perturbed slightly to obtain a better fit to the single-particle transfer strengths. In Ref. 6 the supersymmetry was perturbed numerically by a lowering of the strength of the boson-fermion coupling (to about one-half of the value required by the supersymmetry) and by introduction of an  $s_{1/2}$  particle. This yielded better agreement between theory and experiment for the single-particle transfer strengths. However, when one examines the  $\gamma$ -ray deexcitation predictions of these calculations, the Spin(6)  $E2$  selection rules are preserved, except for the deexcitation of the  $\sigma = \frac{11}{2}, \frac{3}{2}^+$  state, which now has an allowed transition to the ground state, preserving the  $\tau$  selection rule, while violating  $\Delta\sigma = 0$ . In consequence, one can readily assign Spin(6) quantum numbers to states predicted in the perturbed calculations, and one obtains

the same correspondence between theory and experiment as that obtained with the unperturbed supersymmetry predictions presented here.

In summary, recent measurements of electromagnetic transitions in  $^{195}\text{Ir}$  have allowed a more detailed examination of the structure of nuclei in regions where the  $U(6/4) \supset \text{Spin}(6)$  symmetry is expected to be important. The low-lying pattern of energy levels is repeated starting at  $\approx 250$  keV, a structure that is readily reproduced if we assume a boson-fermion symmetry which permits a straightforward labeling of states with  $(\sigma, \tau)$  quantum numbers. The spectrum of  $^{195}\text{Ir}$  thus provides the most extensive identification of  $\sigma < \sigma_{\max}$  states in a nucleus with  $U(6/4) \supset \text{Spin}(6)$  symmetry and these are the states which are the unique signature of  $O(6)$  symmetry. The single-particle strengths for the population of these levels may provide the most sensitive test of the details of the new boson-fermion symmetries, since with the simplest transfer operator,  $a^\dagger$ , the single-particle character of the wave functions is probed. However, that the basic structure of these symmetries can be identified from the behavior of the energy spacings and electromagnetic transitions, even in nuclei which do not strictly follow the single-particle predictions, points to the applicability and usefulness of these new symmetries and supersymmetries to a wider range of nuclei.

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P-1 National Security Classified Information [(a)(1) of the PRA]  
P-2 Relating to the appointment to Federal office [(a)(2) of the PRA]  
P-3 Release would violate a Federal statute [(a)(3) of the PRA]  
P-4 Release would disclose trade secrets or confidential commercial or financial information [(a)(4) of the PRA]  
P-5 Release would disclose confidential advice between the President and his advisors, or between such advisors [(a)(5) of the PRA]  
P-6 Release would constitute a clearly unwarranted invasion of personal privacy [(a)(6) of the PRA]

C. Closed in accordance with restrictions contained in donor's deed of gift.

PRM. Removed as a personal record misfile.

**Freedom of Information Act - [5 U.S.C. 552(b)]**

(b)(1) National security classified information [(b)(1) of the FOIA]  
(b)(2) Release would disclose internal personnel rules and practices of an agency [(b)(2) of the FOIA]  
(b)(3) Release would violate a Federal statute [(b)(3) of the FOIA]  
(b)(4) Release would disclose trade secrets or confidential or financial information [(b)(4) of the FOIA]  
(b)(6) Release would constitute a clearly unwarranted invasion of personal privacy [(b)(6) of the FOIA]  
(b)(7) Release would disclose information compiled for law enforcement purposes [(b)(7) of the FOIA]  
(b)(8) Release would disclose information concerning the regulation of financial institutions [(b)(8) of the FOIA]  
(b)(9) Release would disclose geological or geophysical information

"CORRESPONDENCE TRACKING"

TYPE: INFORMATION  
ORIGINATOR: 02

DOCUMENT NUMBER: 9124165  
DIRECTORATE STATUS

STATUS C

\*\*\*\*\*

FROM: WERT, James J.: VANDERBILT UNIVERSITY

TO: DR. D.A. BROMLEY

DATE OF  
CORRESPONDENCE: 09/16/91

SUBJECT: A THANK YOU FOR YOUR EVALUATION OF DR. ROBERT A.  
WELLER.

\*\*\*\*\*  
DIRECTORATE  
ASSIGNED: STAFF  
ASSIGNED:

ACTION  
REQUIRED: STAFF  
ACTION:

\*\*\*\*\*  
OSTP DUE DATE: SENDER'S DUE DATE:  
DATE COMPLETED: STAFF DUE DATE  
DATE COMPLETED/DEPT:

\*\*\*\*\*

COPIES TO: D. Allan Bromley

\*\*\*\*\*

WHITE HOUSE TRACKING #:

CONTACT PERSON:

REMARKS:

PHONE:

EXT:

OSTP RECEIVED: 09/24/91  
DEPT RECEIVED:

FILE: P-DAB-REFERRAL



# Withdrawal/Redaction Sheet

## (George Bush Library)

| Document No.<br>and Type | Subject/Title of Document                                                                       | Date    | Restriction | Class. |
|--------------------------|-------------------------------------------------------------------------------------------------|---------|-------------|--------|
| 03a. Letter              | To: Allan Bromley From: James Wert<br>Re: Robert Weller [personal information redacted] (1 pp.) | 9/16/91 | (b)(6)      |        |

**Collection:**

**Record Group:** Bush Presidential Records  
**Office:** Science and Technology Policy, Office of (OSTP)  
**Series:** Bromley, D. Allan, Files  
**Subseries:** Correspondence Files  
**WHORM Cat.:**  
**File Location:** D. Allan Bromley - Referral [3 of 6] [1991]

|                               |             |                             |           |
|-------------------------------|-------------|-----------------------------|-----------|
| <b>Date Closed:</b>           | 2/11/2010   | <b>OA/ID Number:</b>        | 62006-003 |
| <b>FOIA/SYS Case #:</b>       | 2005-0336-F | <b>Appeal Case #:</b>       |           |
| <b>Re-review Case #:</b>      |             | <b>Appeal Disposition:</b>  |           |
| <b>P-2/P-5 Review Case #:</b> |             | <b>Disposition Date:</b>    |           |
| <b>AR Case #:</b>             |             | <b>MR Case #:</b>           |           |
| <b>AR Disposition:</b>        |             | <b>MR Disposition:</b>      |           |
| <b>AR Disposition Date:</b>   |             | <b>MR Disposition Date:</b> |           |

### RESTRICTION CODES

**Presidential Records Act - [44 U.S.C. 2204(a)]**

P-1 National Security Classified Information [(a)(1) of the PRA]  
P-2 Relating to the appointment to Federal office [(a)(2) of the PRA]  
P-3 Release would violate a Federal statute [(a)(3) of the PRA]  
P-4 Release would disclose trade secrets or confidential commercial or financial information [(a)(4) of the PRA]  
P-5 Release would disclose confidential advice between the President and his advisors, or between such advisors [(a)(5) of the PRA]  
P-6 Release would constitute a clearly unwarranted invasion of personal privacy [(a)(6) of the PRA]

C. Closed in accordance with restrictions contained in donor's deed of gift.

PRM. Removed as a personal record misfile.

**Freedom of Information Act - [5 U.S.C. 552(b)]**

(b)(1) National security classified information [(b)(1) of the FOIA]  
(b)(2) Release would disclose internal personnel rules and practices of an agency [(b)(2) of the FOIA]  
(b)(3) Release would violate a Federal statute [(b)(3) of the FOIA]  
(b)(4) Release would disclose trade secrets or confidential or financial information [(b)(4) of the FOIA]  
(b)(6) Release would constitute a clearly unwarranted invasion of personal privacy [(b)(6) of the FOIA]  
(b)(7) Release would disclose information compiled for law enforcement purposes [(b)(7) of the FOIA]  
(b)(8) Release would disclose information concerning the regulation of financial institutions [(b)(8) of the FOIA]  
(b)(9) Release would disclose geological or geophysical information

# Withdrawal/Redaction Sheet

## (George Bush Library)

| Document No.<br>and Type | Subject/Title of Document                                                                                      | Date     | Restriction | Class. |
|--------------------------|----------------------------------------------------------------------------------------------------------------|----------|-------------|--------|
| 03b. Letter              | To: Robert Weller From: Allan Bromley<br>Re: letter from James Wert [personal information redacted]<br>(1 pp.) | 11/29/91 | (b)(6)      |        |

**Collection:**

**Record Group:** Bush Presidential Records  
**Office:** Science and Technology Policy, Office of (OSTP)  
**Series:** Bromley, D. Allan, Files  
**Subseries:** Correspondence Files  
**WHORM Cat.:**  
**File Location:** D. Allan Bromley - Referral [3 of 6] [1991]

|                               |             |                             |           |
|-------------------------------|-------------|-----------------------------|-----------|
| <b>Date Closed:</b>           | 2/11/2010   | <b>OA/ID Number:</b>        | 62006-003 |
| <b>FOIA/SYS Case #:</b>       | 2005-0336-F | <b>Appeal Case #:</b>       |           |
| <b>Re-review Case #:</b>      |             | <b>Appeal Disposition:</b>  |           |
| <b>P-2/P-5 Review Case #:</b> |             | <b>Disposition Date:</b>    |           |
| <b>AR Case #:</b>             |             | <b>MR Case #:</b>           |           |
| <b>AR Disposition:</b>        |             | <b>MR Disposition:</b>      |           |
| <b>AR Disposition Date:</b>   |             | <b>MR Disposition Date:</b> |           |

### RESTRICTION CODES

Presidential Records Act - [44 U.S.C. 2204(a)]

P-1 National Security Classified Information [(a)(1) of the PRA]  
P-2 Relating to the appointment to Federal office [(a)(2) of the PRA]  
P-3 Release would violate a Federal statute [(a)(3) of the PRA]  
P-4 Release would disclose trade secrets or confidential commercial or financial information [(a)(4) of the PRA]  
P-5 Release would disclose confidential advice between the President and his advisors, or between such advisors [(a)(5) of the PRA]  
P-6 Release would constitute a clearly unwarranted invasion of personal privacy [(a)(6) of the PRA]

C. Closed in accordance with restrictions contained in donor's deed of gift.

PRM. Removed as a personal record misfile.

Freedom of Information Act - [5 U.S.C. 552(b)]

(b)(1) National security classified information [(b)(1) of the FOIA]  
(b)(2) Release would disclose internal personnel rules and practices of an agency [(b)(2) of the FOIA]  
(b)(3) Release would violate a Federal statute [(b)(3) of the FOIA]  
(b)(4) Release would disclose trade secrets or confidential or financial information [(b)(4) of the FOIA]  
(b)(6) Release would constitute a clearly unwarranted invasion of personal privacy [(b)(6) of the FOIA]  
(b)(7) Release would disclose information compiled for law enforcement purposes [(b)(7) of the FOIA]  
(b)(8) Release would disclose information concerning the regulation of financial institutions [(b)(8) of the FOIA]  
(b)(9) Release would disclose geological or geophysical information



"CORRESPONDENCE TRACKING"

TYPE: ACTION DOCUMENT NUMBER: 9124075  
ORIGINATOR: 02 STATUS I DIRECTORATE STATUS  
\*\*\*\*\*

FROM: AUSUBEL, Jesse H.: THE ROCKEFELLER UNIVERSITY

TO: DR. D.A. BROMLEY

DATE OF  
CORRESPONDENCE: 09/11/91

SUBJECT: A REMINDER ABOUT THE 07/26/91 REQUEST FOR A LETTER  
OF SUPPORT OF BOB WHITE'S NOMINATION FOR THE TYLER  
PRIZE BY OCTOBER 1.

\*\*\*\*\*  
DIRECTORATE STAFF  
ASSIGNED: D. Allan Bromley ASSIGNED:

ACTION STAFF  
REQUIRED: AS NECESSARY ACTION:

\*\*\*\*\*  
SENDER'S DUE DATE: STAFF DUE DATE  
OSTP DUE DATE: 09/24/91  
DATE COMPLETED: DATE COMPLETED/DEPT:

\*\*\*\*\*  
COPIES TO:

\*\*\*\*\*  
WHITE HOUSE TRACKING #: CONTACT PERSON:  
REMARKS: PHONE: EXT:

CLOSED

OSTP RECEIVED: 09/18/91 FILE: P-DAB-REFERRAL  
DEPT RECEIVED:



# Withdrawal/Redaction Sheet

## (George Bush Library)

| Document No.<br>and Type | Subject/Title of Document                                                                                                      | Date    | Restriction | Class. |
|--------------------------|--------------------------------------------------------------------------------------------------------------------------------|---------|-------------|--------|
| 04a. Letter              | To: Jesse Audubel From: Allan Bromley<br>Re: Letter of Recommendation for Bob White [personal<br>information redacted] (1 pp.) | 9/20/91 | (b)(6)      |        |

**Collection:**

**Record Group:** Bush Presidential Records  
**Office:** Science and Technology Policy, Office of (OSTP)  
**Series:** Bromley, D. Allan, Files  
**Subseries:** Correspondence Files  
**WHORM Cat.:**  
**File Location:** D. Allan Bromley - Referral [3 of 6] [1991]

|                               |             |                             |           |
|-------------------------------|-------------|-----------------------------|-----------|
| <b>Date Closed:</b>           | 2/11/2010   | <b>OA/ID Number:</b>        | 62006-003 |
| <b>FOIA/SYS Case #:</b>       | 2005-0336-F | <b>Appeal Case #:</b>       |           |
| <b>Re-review Case #:</b>      |             | <b>Appeal Disposition:</b>  |           |
| <b>P-2/P-5 Review Case #:</b> |             | <b>Disposition Date:</b>    |           |
| <b>AR Case #:</b>             |             | <b>MR Case #:</b>           |           |
| <b>AR Disposition:</b>        |             | <b>MR Disposition:</b>      |           |
| <b>AR Disposition Date:</b>   |             | <b>MR Disposition Date:</b> |           |

### RESTRICTION CODES

**Presidential Records Act - [44 U.S.C. 2204(a)]**

P-1 National Security Classified Information [(a)(1) of the PRA]  
P-2 Relating to the appointment to Federal office [(a)(2) of the PRA]  
P-3 Release would violate a Federal statute [(a)(3) of the PRA]  
P-4 Release would disclose trade secrets or confidential commercial or  
financial information [(a)(4) of the PRA]  
P-5 Release would disclose confidential advice between the President  
and his advisors, or between such advisors [(a)(5) of the PRA]  
P-6 Release would constitute a clearly unwarranted invasion of  
personal privacy [(a)(6) of the PRA]

C. Closed in accordance with restrictions contained in donor's deed of  
gift.

PRM. Removed as a personal record misfile.

**Freedom of Information Act - [5 U.S.C. 552(b)]**

(b)(1) National security classified information [(b)(1) of the FOIA]  
(b)(2) Release would disclose internal personnel rules and practices of an  
agency [(b)(2) of the FOIA]  
(b)(3) Release would violate a Federal statute [(b)(3) of the FOIA]  
(b)(4) Release would disclose trade secrets or confidential or financial  
information [(b)(4) of the FOIA]  
(b)(6) Release would constitute a clearly unwarranted invasion of  
personal privacy [(b)(6) of the FOIA]  
(b)(7) Release would disclose information compiled for law enforcement  
purposes [(b)(7) of the FOIA]  
(b)(8) Release would disclose information concerning the regulation of  
financial institutions [(b)(8) of the FOIA]  
(b)(9) Release would disclose geological or geophysical information



# Withdrawal/Redaction Sheet

## (George Bush Library)

| Document No.<br>and Type | Subject/Title of Document                                                                                                         | Date    | Restriction | Class. |
|--------------------------|-----------------------------------------------------------------------------------------------------------------------------------|---------|-------------|--------|
| 04b. Letter              | To: Jerome Walker From: Allan Bromley<br>Re: Letter of Recommendation for Robert White [personal<br>information redacted] (2 pp.) | 9/19/91 | (b)(6)      |        |

### Collection:

**Record Group:** Bush Presidential Records  
**Office:** Science and Technology Policy, Office of (OSTP)  
**Series:** Bromley, D. Allan, Files  
**Subseries:** Correspondence Files  
**WHORM Cat.:**  
**File Location:** D. Allan Bromley - Referral [3 of 6] [1991]

|                               |             |                             |           |
|-------------------------------|-------------|-----------------------------|-----------|
| <b>Date Closed:</b>           | 2/11/2010   | <b>OA/ID Number:</b>        | 62006-003 |
| <b>FOIA/SYS Case #:</b>       | 2005-0336-F | <b>Appeal Case #:</b>       |           |
| <b>Re-review Case #:</b>      |             | <b>Appeal Disposition:</b>  |           |
| <b>P-2/P-5 Review Case #:</b> |             | <b>Disposition Date:</b>    |           |
| <b>AR Case #:</b>             |             | <b>MR Case #:</b>           |           |
| <b>AR Disposition:</b>        |             | <b>MR Disposition:</b>      |           |
| <b>AR Disposition Date:</b>   |             | <b>MR Disposition Date:</b> |           |

### RESTRICTION CODES

#### Presidential Records Act - [44 U.S.C. 2204(a)]

P-1 National Security Classified Information [(a)(1) of the PRA]  
P-2 Relating to the appointment to Federal office [(a)(2) of the PRA]  
P-3 Release would violate a Federal statute [(a)(3) of the PRA]  
P-4 Release would disclose trade secrets or confidential commercial or  
financial information [(a)(4) of the PRA]  
P-5 Release would disclose confidential advice between the President  
and his advisors, or between such advisors [(a)(5) of the PRA]  
P-6 Release would constitute a clearly unwarranted invasion of  
personal privacy [(a)(6) of the PRA]

C. Closed in accordance with restrictions contained in donor's deed of  
gift.

PRM. Removed as a personal record misfile.

#### Freedom of Information Act - [5 U.S.C. 552(b)]

(b)(1) National security classified information [(b)(1) of the FOIA]  
(b)(2) Release would disclose internal personnel rules and practices of an  
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(b)(4) Release would disclose trade secrets or confidential or financial  
information [(b)(4) of the FOIA]  
(b)(6) Release would constitute a clearly unwarranted invasion of  
personal privacy [(b)(6) of the FOIA]  
(b)(7) Release would disclose information compiled for law enforcement  
purposes [(b)(7) of the FOIA]  
(b)(8) Release would disclose information concerning the regulation of  
financial institutions [(b)(8) of the FOIA]  
(b)(9) Release would disclose geological or geophysical information



1230 YORK AVENUE • NEW YORK, NEW YORK 10021-6399

RECEIVED  
SEP 22 11  
OFFICE OF THE  
DIRECTOR

September 11, 1991

Dear Allan,

Just a reminder -- if you can get a letter of support of Bob White's nomination for the Tyler Prize by October 1, it would be much appreciated.

Sincerely,

Jesse Ausubel

Attachment: July 26 letter



# Withdrawal/Redaction Sheet

## (George Bush Library)

| Document No.<br>and Type | Subject/Title of Document                                                                                                                  | Date    | Restriction | Class. |
|--------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|---------|-------------|--------|
| 04c. Letter              | To: Allan Bromley From: Jesse Ausubel<br>Re: Requests Letter of Recommendation for Robert White<br>[personal information redacted] (1 pp.) | 7/26/91 | (b)(6)      |        |

**Collection:**

**Record Group:** Bush Presidential Records  
**Office:** Science and Technology Policy, Office of (OSTP)  
**Series:** Bromley, D. Allan, Files  
**Subseries:** Correspondence Files  
**WHORM Cat.:**  
**File Location:** D. Allan Bromley - Referral [3 of 6] [1991]

|                               |             |                             |           |
|-------------------------------|-------------|-----------------------------|-----------|
| <b>Date Closed:</b>           | 2/11/2010   | <b>OA/ID Number:</b>        | 62006-003 |
| <b>FOIA/SYS Case #:</b>       | 2005-0336-F | <b>Appeal Case #:</b>       |           |
| <b>Re-review Case #:</b>      |             | <b>Appeal Disposition:</b>  |           |
| <b>P-2/P-5 Review Case #:</b> |             | <b>Disposition Date:</b>    |           |
| <b>AR Case #:</b>             |             | <b>MR Case #:</b>           |           |
| <b>AR Disposition:</b>        |             | <b>MR Disposition:</b>      |           |
| <b>AR Disposition Date:</b>   |             | <b>MR Disposition Date:</b> |           |

### RESTRICTION CODES

Presidential Records Act - [44 U.S.C. 2204(a)]

P-1 National Security Classified Information [(a)(1) of the PRA]  
P-2 Relating to the appointment to Federal office [(a)(2) of the PRA]  
P-3 Release would violate a Federal statute [(a)(3) of the PRA]  
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P-5 Release would disclose confidential advice between the President and his advisors, or between such advisors [(a)(5) of the PRA]  
P-6 Release would constitute a clearly unwarranted invasion of personal privacy [(a)(6) of the PRA]

C. Closed in accordance with restrictions contained in donor's deed of gift.

PRM. Removed as a personal record misfile.

Freedom of Information Act - [5 U.S.C. 552(b)]

(b)(1) National security classified information [(b)(1) of the FOIA]  
(b)(2) Release would disclose internal personnel rules and practices of an agency [(b)(2) of the FOIA]  
(b)(3) Release would violate a Federal statute [(b)(3) of the FOIA]  
(b)(4) Release would disclose trade secrets or confidential or financial information [(b)(4) of the FOIA]  
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(b)(7) Release would disclose information compiled for law enforcement purposes [(b)(7) of the FOIA]  
(b)(8) Release would disclose information concerning the regulation of financial institutions [(b)(8) of the FOIA]  
(b)(9) Release would disclose geological or geophysical information



"CORRESPONDENCE TRACKING"

TYPE: ACTION DOCUMENT NUMBER: 9124073  
ORIGINATOR: 02 STATUS I DIRECTORATE STATUS  
\*\*\*\*\*

FROM: STRAYER, Michael R.: OAK RIDGE NATIONAL LABORATORY

TO: DR. D.A. BROMLEY

DATE OF  
CORRESPONDENCE: 09/10/91

SUBJECT: REQUEST TO WRITE A LETTER OF RECOMMENDATION TO  
SUPPORT THE PROMOTION TO RAY SATCHLER TO THE POSITION  
OF SENIOR CORPORATE FELLOW

\*\*\*\*\*  
DIRECTORATE STAFF  
ASSIGNED: D. Allan Bromley ASSIGNED:

ACTION STAFF  
REQUIRED: AS NECESSARY ACTION:

\*\*\*\*\*  
SENDER'S DUE DATE:  
OSTP DUE DATE: 10/01/91 STAFF DUE DATE  
DATE COMPLETED: DATE COMPLETED/DEPT:

\*\*\*\*\*  
COPIES TO:

\*\*\*\*\*  
WHITE HOUSE TRACKING #: CONTACT PERSON:  
REMARKS: PHONE: EXT:

CLOSED

OSTP RECEIVED: 09/17/91 FILE: 0-DAB-REFERRAL  
DEPT RECEIVED:



# Withdrawal/Redaction Sheet

## (George Bush Library)

| Document No.<br>and Type | Subject/Title of Document                                                                                                             | Date    | Restriction | Class. |
|--------------------------|---------------------------------------------------------------------------------------------------------------------------------------|---------|-------------|--------|
| 05a. Letter              | To: Alvin Trivelpiece From: Allan Bromley<br>Re: Letter of Recommendation for Ray Stachler [personal<br>information redacted] (2 pp.) | 12/2/91 | (b)(6)      |        |

**Collection:**

**Record Group:** Bush Presidential Records  
**Office:** Science and Technology Policy, Office of (OSTP)  
**Series:** Bromley, D. Allan, Files  
**Subseries:** Correspondence Files  
**WHORM Cat.:**  
**File Location:** D. Allan Bromley - Referral [3 of 6] [1991]

|                               |             |                             |           |
|-------------------------------|-------------|-----------------------------|-----------|
| <b>Date Closed:</b>           | 2/11/2010   | <b>OA/ID Number:</b>        | 62006-003 |
| <b>FOIA/SYS Case #:</b>       | 2005-0336-F | <b>Appeal Case #:</b>       |           |
| <b>Re-review Case #:</b>      |             | <b>Appeal Disposition:</b>  |           |
| <b>P-2/P-5 Review Case #:</b> |             | <b>Disposition Date:</b>    |           |
| <b>AR Case #:</b>             |             | <b>MR Case #:</b>           |           |
| <b>AR Disposition:</b>        |             | <b>MR Disposition:</b>      |           |
| <b>AR Disposition Date:</b>   |             | <b>MR Disposition Date:</b> |           |

### RESTRICTION CODES

**Presidential Records Act - [44 U.S.C. 2204(a)]**

P-1 National Security Classified Information [(a)(1) of the PRA]  
P-2 Relating to the appointment to Federal office [(a)(2) of the PRA]  
P-3 Release would violate a Federal statute [(a)(3) of the PRA]  
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financial information [(a)(4) of the PRA]  
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and his advisors, or between such advisors [(a)(5) of the PRA]  
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personal privacy [(a)(6) of the PRA]

C. Closed in accordance with restrictions contained in donor's deed of  
gift.

PRM. Removed as a personal record misfile.

**Freedom of Information Act - [5 U.S.C. 552(b)]**

(b)(1) National security classified information [(b)(1) of the FOIA]  
(b)(2) Release would disclose internal personnel rules and practices of an  
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purposes [(b)(7) of the FOIA]  
(b)(8) Release would disclose information concerning the regulation of  
financial institutions [(b)(8) of the FOIA]  
(b)(9) Release would disclose geological or geophysical information

# Withdrawal/Redaction Sheet

## (George Bush Library)

| Document No.<br>and Type | Subject/Title of Document                                                                                                                    | Date    | Restriction | Class. |
|--------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|---------|-------------|--------|
| 05b. Letter              | To: Allan Bromley From: Michael Strayer<br>Re: Requests Letter of Recommendation for Ray Satchler<br>[personal information redacted] (1 pp.) | 9/10/91 | (b)(6)      |        |

### Collection:

**Record Group:** Bush Presidential Records  
**Office:** Science and Technology Policy, Office of (OSTP)  
**Series:** Bromley, D. Allan, Files  
**Subseries:** Correspondence Files  
**WHORM Cat.:**  
**File Location:** D. Allan Bromley - Referral [3 of 6] [1991]

|                               |             |                             |           |
|-------------------------------|-------------|-----------------------------|-----------|
| <b>Date Closed:</b>           | 2/11/2010   | <b>OA/ID Number:</b>        | 62006-003 |
| <b>FOIA/SYS Case #:</b>       | 2005-0336-F | <b>Appeal Case #:</b>       |           |
| <b>Re-review Case #:</b>      |             | <b>Appeal Disposition:</b>  |           |
| <b>P-2/P-5 Review Case #:</b> |             | <b>Disposition Date:</b>    |           |
| <b>AR Case #:</b>             |             | <b>MR Case #:</b>           |           |
| <b>AR Disposition:</b>        |             | <b>MR Disposition:</b>      |           |
| <b>AR Disposition Date:</b>   |             | <b>MR Disposition Date:</b> |           |

### RESTRICTION CODES

#### Presidential Records Act - [44 U.S.C. 2204(a)]

P-1 National Security Classified Information [(a)(1) of the PRA]  
 P-2 Relating to the appointment to Federal office [(a)(2) of the PRA]  
 P-3 Release would violate a Federal statute [(a)(3) of the PRA]  
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 P-5 Release would disclose confidential advice between the President and his advisors, or between such advisors [(a)(5) of the PRA]  
 P-6 Release would constitute a clearly unwarranted invasion of personal privacy [(a)(6) of the PRA]

C. Closed in accordance with restrictions contained in donor's deed of gift.

PRM. Removed as a personal record misfile.

#### Freedom of Information Act - [5 U.S.C. 552(b)]

(b)(1) National security classified information [(b)(1) of the FOIA]  
 (b)(2) Release would disclose internal personnel rules and practices of an agency [(b)(2) of the FOIA]  
 (b)(3) Release would violate a Federal statute [(b)(3) of the FOIA]  
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 (b)(7) Release would disclose information compiled for law enforcement purposes [(b)(7) of the FOIA]  
 (b)(8) Release would disclose information concerning the regulation of financial institutions [(b)(8) of the FOIA]  
 (b)(9) Release would disclose geological or geophysical information



"Document Control"

TYPE: ACTION  
ORIGINATOR: 02

DOCUMENT NUMBER: 9203145  
DIRECTORATE STATUS

\*\*\*\*\*

FROM: NEY, EDWARD N.

TO: DAB

DATE OF  
CORRESPONDENCE: 09/16/91

SUBJECT: RE: THE NOMINATION OF SAUL J. FARBER FOR THE  
PRESIDENT'S NATIONAL MEDAL OF SCIENCE

\*\*\*\*\*

DIRECTORATE  
ASSIGNED: D. Allan Bromley

STAFF  
ASSIGNED:

ACTION  
REQUIRED: AS NECESSARY

STAFF  
ACTION:

\*\*\*\*\*

SENDER'S DUE DATE:

OSTP DUE DATE:  
DATE COMPLETED:

STAFF DUE DATE  
DATE COMPLETED/DEPT:

\*\*\*\*\*

COPIES TO:

\*\*\*\*\*

WHITE HOUSE TRACKING #:

CONTACT PERSON:  
PHONE:

EXT:

REMARKS:

OSTP RECEIVED: 04/22/92

DEPT RECEIVED:

FILE: P-REFERRAL

CENTRAL FILES:

THE WHITE HOUSE  
WASHINGTON

**TO:** Dr. D. Allan Bromley

**FROM:** **SUSAN PORTER ROSE**  
**Chief of Staff to Mrs. Bush**  
**456-2957**

☐ For Your Information

☒ For Your Action and as we discussed.

☐ For Your Files

☐ As Requested

☐ For Your Comments and Suggestions

☐ Let's Discuss

☐ Please Return



3145

NATIONAL SCIENCE BOARD  
National Science Foundation  
Washington, D.C. 20550

FACSIMILE

TO: *DAMAR*

ORGANIZATION: *OSTD*

FAX NUMBER: *395-3261*

TELEPHONE NUMBER:

FROM: Susan E. Fannoney *Susan*

FAX NUMBER: 202-357-7346

PHONE NUMBER: 202-357-7512

Number of pages excluding cover sheet: *1*

COMMENTS:

*Draft response to Ambassador Ney.  
Please send me copy of Ney's letter  
and Brumley's response so I can put  
in Farber's file.*

*— Call me re dinner program —*

# Withdrawal/Redaction Sheet

## (George Bush Library)

| Document No.<br>and Type | Subject/Title of Document                                                                                                                      | Date    | Restriction | Class. |
|--------------------------|------------------------------------------------------------------------------------------------------------------------------------------------|---------|-------------|--------|
| 06a. Letter              | To: Committee on the National Medal of Science From:<br>Edward Ney<br>Re: Nomination of Saul Farber [personal information<br>redacted] (1 pp.) | 9/16/91 | (b)(6)      |        |

**Collection:**

**Record Group:** Bush Presidential Records  
**Office:** Science and Technology Policy, Office of (OSTP)  
**Series:** Bromley, D. Allan, Files  
**Subseries:** Correspondence Files  
**WHORM Cat.:**  
**File Location:** D. Allan Bromley - Referral [3 of 6] [1991]

|                               |             |                             |           |
|-------------------------------|-------------|-----------------------------|-----------|
| <b>Date Closed:</b>           | 2/11/2010   | <b>OA/ID Number:</b>        | 62006-003 |
| <b>FOIA/SYS Case #:</b>       | 2005-0336-F | <b>Appeal Case #:</b>       |           |
| <b>Re-review Case #:</b>      |             | <b>Appeal Disposition:</b>  |           |
| <b>P-2/P-5 Review Case #:</b> |             | <b>Disposition Date:</b>    |           |
| <b>AR Case #:</b>             |             | <b>MR Case #:</b>           |           |
| <b>AR Disposition:</b>        |             | <b>MR Disposition:</b>      |           |
| <b>AR Disposition Date:</b>   |             | <b>MR Disposition Date:</b> |           |

### RESTRICTION CODES

Presidential Records Act - [44 U.S.C. 2204(a)]

P-1 National Security Classified Information [(a)(1) of the PRA]  
P-2 Relating to the appointment to Federal office [(a)(2) of the PRA]  
P-3 Release would violate a Federal statute [(a)(3) of the PRA]  
P-4 Release would disclose trade secrets or confidential commercial or  
financial information [(a)(4) of the PRA]  
P-5 Release would disclose confidential advice between the President  
and his advisors, or between such advisors [(a)(5) of the PRA]  
P-6 Release would constitute a clearly unwarranted invasion of  
personal privacy [(a)(6) of the PRA]

C. Closed in accordance with restrictions contained in donor's deed of  
gift.

PRM. Removed as a personal record misfile.

Freedom of Information Act - [5 U.S.C. 552(b)]

(b)(1) National security classified information [(b)(1) of the FOIA]  
(b)(2) Release would disclose internal personnel rules and practices of an  
agency [(b)(2) of the FOIA]  
(b)(3) Release would violate a Federal statute [(b)(3) of the FOIA]  
(b)(4) Release would disclose trade secrets or confidential or financial  
information [(b)(4) of the FOIA]  
(b)(6) Release would constitute a clearly unwarranted invasion of  
personal privacy [(b)(6) of the FOIA]  
(b)(7) Release would disclose information compiled for law enforcement  
purposes [(b)(7) of the FOIA]  
(b)(8) Release would disclose information concerning the regulation of  
financial institutions [(b)(8) of the FOIA]  
(b)(9) Release would disclose geological or geophysical information



# Withdrawal/Redaction Sheet

## (George Bush Library)

| Document No.<br>and Type | Subject/Title of Document                                                                                  | Date    | Restriction | Class. |
|--------------------------|------------------------------------------------------------------------------------------------------------|---------|-------------|--------|
| 06b. Letter              | To: Barbara Bush From: Edward Ney<br>Re: Nomination of Saul Farber [personal information redacted] (1 pp.) | 4/28/92 | (b)(6)      |        |

**Collection:**

**Record Group:** Bush Presidential Records  
**Office:** Science and Technology Policy, Office of (OSTP)  
**Series:** Bromley, D. Allan, Files  
**Subseries:** Correspondence Files  
**WHORM Cat.:**  
**File Location:** D. Allan Bromley - Referral [3 of 6] [1991]

|                               |             |                             |           |
|-------------------------------|-------------|-----------------------------|-----------|
| <b>Date Closed:</b>           | 2/11/2010   | <b>OA/ID Number:</b>        | 62006-003 |
| <b>FOIA/SYS Case #:</b>       | 2005-0336-F | <b>Appeal Case #:</b>       |           |
| <b>Re-review Case #:</b>      |             | <b>Appeal Disposition:</b>  |           |
| <b>P-2/P-5 Review Case #:</b> |             | <b>Disposition Date:</b>    |           |
| <b>AR Case #:</b>             |             | <b>MR Case #:</b>           |           |
| <b>AR Disposition:</b>        |             | <b>MR Disposition:</b>      |           |
| <b>AR Disposition Date:</b>   |             | <b>MR Disposition Date:</b> |           |

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(b)(7) Release would disclose information compiled for law enforcement purposes [(b)(7) of the FOIA]  
(b)(8) Release would disclose information concerning the regulation of financial institutions [(b)(8) of the FOIA]  
(b)(9) Release would disclose geological or geophysical information

# Withdrawal/Redaction Sheet

## (George Bush Library)

| Document No.<br>and Type | Subject/Title of Document                                                                                                 | Date    | Restriction | Class. |
|--------------------------|---------------------------------------------------------------------------------------------------------------------------|---------|-------------|--------|
| 06c. Letter              | To: Edward Ney From: Barbara Bush<br>Re: Response to nomination of Saul Farber [personal<br>information redacted] (1 pp.) | 5/12/92 | (b)(6)      |        |

### Collection:

**Record Group:** Bush Presidential Records  
**Office:** Science and Technology Policy, Office of (OSTP)  
**Series:** Bromley, D. Allan, Files  
**Subseries:** Correspondence Files  
**WHORM Cat.:**  
**File Location:** D. Allan Bromley - Referral [3 of 6] [1991]

|                               |             |                             |           |
|-------------------------------|-------------|-----------------------------|-----------|
| <b>Date Closed:</b>           | 2/11/2010   | <b>OA/ID Number:</b>        | 62006-003 |
| <b>FOIA/SYS Case #:</b>       | 2005-0336-F | <b>Appeal Case #:</b>       |           |
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## (George Bush Library)

| Document No.<br>and Type | Subject/Title of Document                                                                                   | Date    | Restriction | Class. |
|--------------------------|-------------------------------------------------------------------------------------------------------------|---------|-------------|--------|
| 06d. Letter              | To: Edward Ney From: Allan Bromley<br>Re: Nomination of Saul Farber [personal information redacted] (1 pp.) | 5/18/92 | (b)(6)      |        |

**Collection:**

**Record Group:** Bush Presidential Records  
**Office:** Science and Technology Policy, Office of (OSTP)  
**Series:** Bromley, D. Allan, Files  
**Subseries:** Correspondence Files  
**WHORM Cat.:**  
**File Location:** D. Allan Bromley - Referral [3 of 6] [1991]

|                               |             |                             |           |
|-------------------------------|-------------|-----------------------------|-----------|
| <b>Date Closed:</b>           | 2/11/2010   | <b>OA/ID Number:</b>        | 62006-003 |
| <b>FOIA/SYS Case #:</b>       | 2005-0336-F | <b>Appeal Case #:</b>       |           |
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