Identification of Single-Particle Configurations at Very High Spin in $^{150-152}$Dy

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Gamma-gamma coincidence studies of $^{150-152}$Dy have been performed with use of Compton-suppressed Ge(Li) detectors to resolve ambiguities in the high-spin structure of these nuclei. On the basis of I^π assignments, transition rates, and level systematics for $^{148-152}$Dy, the observed levels are interpreted as proton particle-hole excitations coupled to aligned valence neutron configurations. The proposed single-particle configurations are confirmed by shell-model calculations.

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Since the observation of very-high-spin states in ^{151}Dy (Ref. 1) and ^{152}Dy (Ref. 2), and recognition of their single-particle nature,[3] a great effort has been made to associate single-particle configurations with the observed levels.[4-6] Early attempts were hampered by incomplete spectroscopic information for the states of highest spin. Nevertheless, fruitful comparisons of levels assembled from valence nucleons in the $N = 85$ (Ref. 7) and $N = 86$ (Ref. 8) isotones have been made, and a picture consisting mainly of neutron transitions has emerged. It is evident, however, that for levels of larger angular momentum, the valence nucleon spin will be exhausted, necessitating excitation of the protons in the core. The nature of the core excitation may be inferred from recent work by the Jülich group studying ^{148}Dy,[9] which has a closed $N = 82$ neutron shell. It thus appears that an understanding of the $I \approx 30$ high-spin states in ^{151,152}Dy could best be obtained from a comparison of the isotopes $^{148-152}$Dy, by tracking the proton core excitation as valence neutrons are added to the closed $N = 82$ shell. This Letter presents the first such systematic identification of these very-high-spin states.

To resolve ambiguities in the high-spin structure of $^{150-152}$Dy, we have performed gamma-gamma coincidence measurements using Compton-suppressed Ge(Li) detectors. Levels were populated via the reactions ^{124}Sn(^{32}S,xn)$^{150-152}$Dy with use of a 1 mg/cm^2 target and a 163-MeV pulsed beam from the Chalk River tandem accelerator. The experimental setup and detailed results will be presented in a subsequent publication.[10]

The results for $^{150-152}$Dy, combined with previous work from this laboratory[1-3] and from Jülich,[11] are shown in Fig. 1(a). The isotopes ^{148,149}Dy (Refs. 9 and 12) are included for comparison. Our level scheme for ^{150}Dy is in substantial agreement with prior work by Ahmad and co-workers.[13] In ^{151,152}Dy, several $E2$ transitions, which were formerly thought[1,2] to be in cascade with the main yrast sequence, have been found to be[10] in parallel with pairs of $M1$ transitions. The level energies of Fig. 1 are shown to scale, taking the energy of the aligned valence configurations $\pi(h_{11/2}{}^2)10^+ \otimes \nu^n$ as a baseline. The experimental information available for these aligned valence configurations, known generally to be isomeric with $t_{1/2} > 1$ ns, is listed in Table I. Note that the parities of the ^{151}Dy$(I = \frac{49}{2})$ and ^{152}Dy$(I = 27)$ isomers have not been measured experimentally. However, much is known about the neutron structure of $N = 85$ (Ref. 7) and $N = 86$ (Ref. 8) nuclei, so that our assumption of the proposed configurations can be made with some confidence. The parity assignments for the higher-lying levels of Fig. 1(a) then follow from knowledge of relative parities.

A striking similarity in spins, parities, and level energies, all relative to the aligned valence configurations, is immediately evident for the Dy isotopes as shown in Fig. 1(a). The $\pi(h_{11/2}{}^3 d_{5/2}{}^{-1})$-$11^-$–$16^-$ and $\pi(h_{11/2}{}^3 g_{7/2}{}^{-1})17^-$ structure in ^{148}Dy has already been established,[9] with the $I^\pi = 11^-$ and 12^- levels identified as having a substantial collective octupole component. Following the various $\pi^3\pi^{-1}$ components from ^{148}Dy to the very high-spin states of ^{151,152}Dy would appear to be possible, as has been indicated in the figure. Those levels which are apparently not a part of this network are drawn as half-length lines.

While the trends shown are visually impressive,

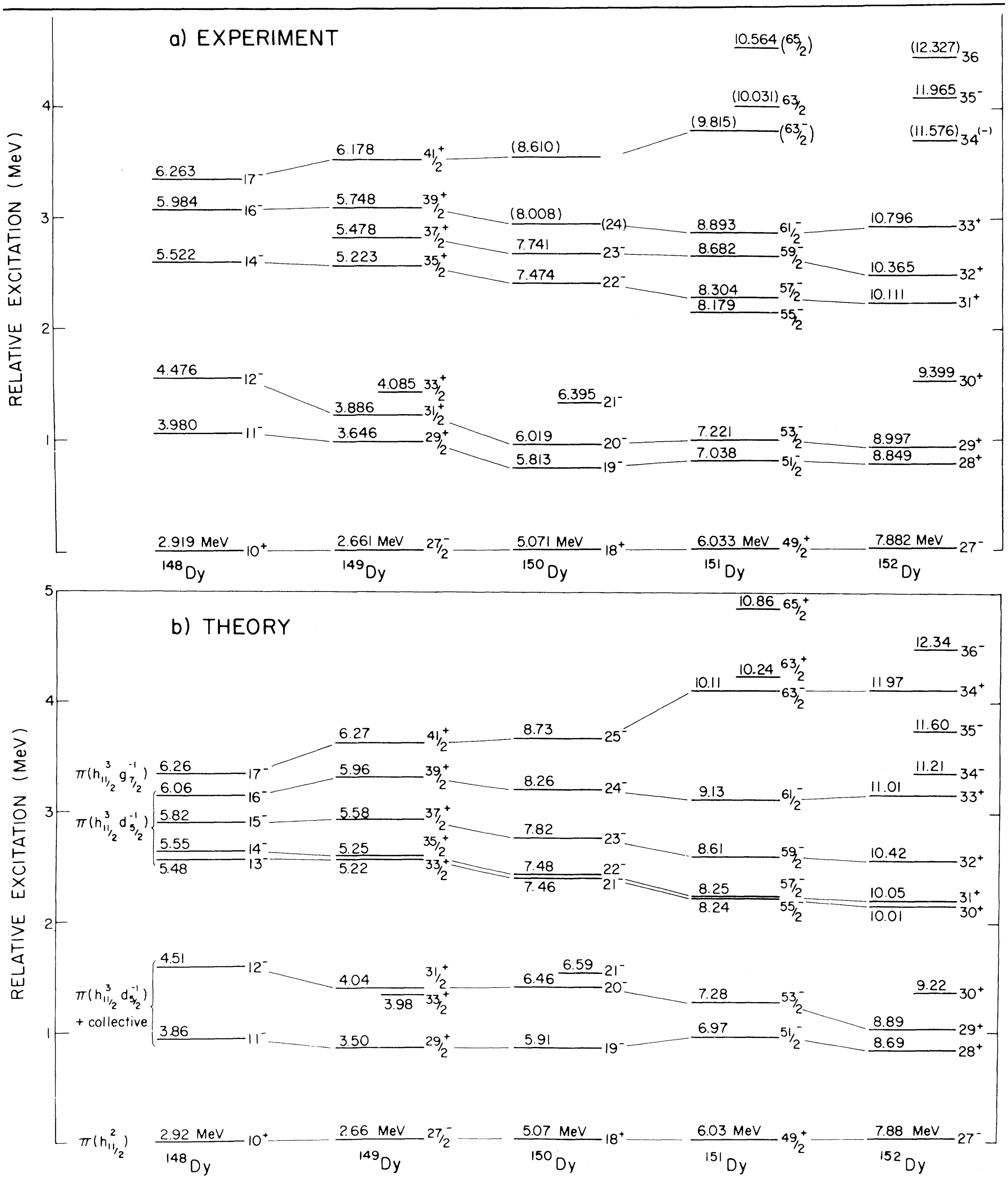

FIG. 1. (a) Experimental energy levels of light Dy isotopes obtained in this experiment and by other workers (see text for references). Excitation energies in MeV relative to the aligned valence nucleon configurations of Table I are indicated by the scale at the left. For each isotope, the absolute level energies are also noted. Uncertain values are in parentheses. Full-length lines represent the levels of ^{148}Dy whose structure is manifested in the other isotopes as valence neutrons are added. Additional energy levels are shown by half-length lines. (b) Shell-model calculations of energy levels of light Dy isotopes. Additional energy levels (half-length lines) are those produced by the substitution of an $i_{13/2}$ neutron for the $f_{7/2}$ neutron in the configurations of Table I. These levels are shown only where one would expect them to be fed strongly by the main gamma-ray cascade.

corroboration of the suggested structure was needed, as well as an explanation for the apparently intruding states at $E = 1.3-1.6$ MeV relative excitation in ^{149,150,152}Dy and for the high-lying states of opposite parity in ^{152}Dy. Accordingly, shell-model computations were performed based on a $^{146}_{64}\mathrm{Gd}_{82}$ closed-shell core. The calculations considered proton configurations of $\pi(h_{11/2}^2)$, $\pi(h_{11/2}^3 d_{5/2}^{-1})$, and $\pi(h_{11/2}^3 g_{7/2}^{-1})$ and neutron configurations of the form $\nu(f_{7/2}^a h_{9/2}^b i_{13/2}^c)$ with $a \leq 2$, $b \leq 1$, $c \leq 2$, and $a+b+c$ equal to the number of valence neutrons. The single-particle energies used by Kleinheinz[11] were adopted for this calculation as was the effective interaction of Schiffer and True.[14] In order that the single-particle calculation reproduce the collective features of the low-lying states, the proton particle-hole matrix elements of Schiffer and True were adjusted to fit the $\pi(h_{11/2}^n d_{5/2}^{-1})$ sextet of states in each of the $N = 82$ nuclei, ^{146}Gd,[11] ^{147}Tb,[11] and ^{148}Dy.[9] Similarly, the neutron–proton-hole interaction was adjusted to the $\nu(f_{7/2})\pi(d_{5/2}^{-1})$ and $\nu(f_{7/2})\pi(g_{7/2}^{-1})$ states in ^{146}Eu (Ref. 15) and the neutron-neutron interaction to the $\nu(f_{7/2}^2)$ states in ^{148}Gd.[11] The remaining matrix elements were left at their Schiffer-True values.

Results of the shell-model calculation are displayed in Fig. 1(b). States of $\pi^3\pi^{-1}$ structure coupled to the neutron configurations of Table I are shown by full-length lines and are connected to corresponding levels in adjacent isotopes. Additional yrast levels, obtained by converting an $f_{7/2}$ neutron to an $i_{13/2}$ neutron, are indicated by half-length lines. The levels of relative excitation energy $E = 1.3-1.6$ MeV mentioned earlier can be seen to be of this type. They occur for $^{149}\mathrm{Dy}[\pi(h_{11/2}^2)\otimes\nu(i_{13/2})]\frac{33}{2}^+$, $^{150}\mathrm{Dy}[\pi(h_{11/2}^2)\otimes\nu(h_{9/2}i_{13/2})]21^-$, and $^{152}\mathrm{Dy}[\pi(h_{11/2}^2)\otimes\nu(f_{7/2}h_{9/2}\times i_{13/2}^2)]30^+$; ^{148}Dy, having no valence neutrons, cannot support such a state, and in ^{151}Dy, the $[\pi(h_{11/2}^2)\otimes\nu(h_{9/2}i_{13/2}^2)]$ level only yields $I^\pi = \frac{53}{2}^-$ which is nonyrast in this range of excitation energy. The higher-lying yrast states of opposite parity are most probably of this variety as well. States having a $(h_{11/2}^3 d_{5/2}^{-1})13^-$ proton component generally lie so close in energy to the $(h_{11/2}^3\times d_{5/2}^{-1})14^-$ component that they are fed very weakly in the yrast cascade. Of these, only the ^{151}Dy $I^\pi = \frac{55}{2}^-$ state is observed experimentally. The overview provided in Fig. 1(b) does indeed confirm that the systematic behavior observed experimentally in the Dy isotopes [Fig. 1(a)] is expected from the proposed proton particle-hole excitations. Quantitatively, the shell-model predictions average within 150 keV of the measured energy levels. This is more than adequate for identifying levels of known spin and parity.

Additional evidence that the similarity in level patterns across the Dy isotopes truly reflects a similarity in the underlying structure may be obtained from the transition rates for corresponding transitions. In ^{151,152}Dy, a detailed analysis of recoil-distance lifetime measurements is available,[3,16] giving absolute $B(M1)$ and $B(E2)$ values. In ^{149,150}Dy relative $M1$ and $E2$ transition strengths or limits may be estimated from branching ratios. Corresponding transitions in $^{149-152}$Dy do indeed show the same range of relative values for the ratio $B(E2: J\to J-2)/B(M1: J\to J-1)$. For example, the decay of the $\pi(16^-)\otimes\nu^n$ levels in ^{149,151,152}Dy gives values of 69, 72, and 87, respectively, for the ratio of reduced transition probabilities in single-particle units. Especially obvious is the hindrance of transitions to the previously discussed states of E(relative) = 1.3 to 1.6 MeV having no proton particle-hole excitation.

In summary, the upgraded level schemes obtained in this work have revealed the similar structures of the light dysprosium isotopes. For the first time, high-spin single-particle configurations are systematically assigned and traced from the well understood states of intermediate spin in the $N = 82$ nucleus ^{148}Dy to the states of very high spin in ^{151,152}Dy. The assignments are

TABLE I. Aligned valence nucleon configurations in the dysprosium isotopes.

Isotope	J^π	E (keV)	$t_{1/2}$	Protons	Neutrons
^{148}Dy	10^+	2919	470 ns	$(h_{11/2}^2)10^+$	(none) 0^+
^{149}Dy	$27/2^-$	2661	0.5 s	$(h_{11/2}^2)10^+$	$(f_{7/2})7/2^-$
^{150}Dy	18^+	5071	···	$(h_{11/2}^2)10^+$	$(f_{7/2}h_{9/2})8^+$
^{151}Dy	$49/2^+$	6033	12.6 ns	$(h_{11/2}^2)10^+$	$(f_{7/2}h_{9/2}i_{13/2})29/2^+$
^{152}Dy	27^-	7882	1.6 ns	$(h_{11/2}^2)10^+$	$(f_{7/2}^2 h_{9/2} i_{13/2})17^-$

supported by the consistent pattern of the energies, spins, and parities of the levels, and by the observed transition rates. Shell-model calculations corroborate the particle-hole nature of the proton excitations and confirm that the most probable decay sequences would preferentially populate the levels observed experimentally.

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