Notas de Física - Volume XIV - Nº 6

SEARCH FOR NEW TRANSITIONS IN THE DECAY OF ^{164}HO

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(Received November 6, 1968)

ABSTRACT: A search for transitions from the 1^{+} ground state of ^{164}Ho to the $2'^{+}$ gamma-vibrational states of ^{164}Dy and ^{164}Er was undertaken. A transition to the 760 keV $2'^{+}$ level of ^{164}Dy with log ft = 8.0 was found. For the transition to the 860 keV ^{164}Er $2'^{+}$ level only a lower limit was found (log ft $\geqslant$ 7.6). The results are discussed in terms of the multiple quasi-particle-pair interpretation of the gamma vibrations.

1. INTRODUCTION

The energy level diagrams of both ^{164}Dy and ^{164}Er present excited 2^+ levels at 760 and 860 keV respectively. These levels have been investigated through (d, p)[1, 2], (p, p')[1], (d,d')[3], (n, γ)[4, 5], (p, 2n)[6] and coulomb excitation [7] reactions, and through the ^{164}Yb - ^{164}Tm decay chain [8]. They are believed to be the heads of gamma-vibrational bands that have recently been interpreted as multiple quasi-particle-pair states [9, 10]. These states could be fed in the decay of ^{164}Ho. Although the decay of ^{164}Ho has been studied quite a number of times [11, 12, 13], no such transitions have been reported. A search for them was undertaken in the present work.

2. EXPERIMENTAL

The ^{164}Ho sources were produced by irradiating the pure oxide or pure metal for about one hour in the bremsstrahlung beam of the 22 MeV electron linear accelerator that was recently constructed at the C.B.P.F. [14]. The average beam current was about 50 μA. The weight of the oxide samples varied from 1 to 3 g; no chemical separations were performed.

The gamma-ray spectra were measured at the C.B.P.F. with a 6 cm^3 Ge-Li detector made in **Strasbourg**[15] and at the I.E.N. with a 22 cm^3 Ge-Li detector made by Ortec which was part of a system that included a 118 A Ortec Preamplifier, a 410 Ortec Amplifier, and a 4096-channel analyzer from Intertechnique. The energy calibration and efficiency of the system is described elsewhere [16]. The resolution of the system was about 6 keV FWHM for the Cs line because of the high counting rate. The energy measurements are estimated to be correct within 0,5 keV.

To measure intensities of the very weak lines an extended sourc of pure Ho metal, measuring about 2 × 3 cm and weighing 1.4 g, was counted at a distance of 2 cm from the detector for 50 min, beginning half an hour after the end of the one hour irradiation. Absorbers (6 mm of Cd and 1 mm Cu) were placed in front of the detector to attenuate the very intense low energy x and γ-rays. To restrain bremsstrahlung production the source was mounted on 2.3 mm of graphite. The same Ho-source was counted for 15 minutes, 3.65 h later, at "standard" geometry, without absorbers, 11 cm away from the detector. Thus the absolute intensity of the source could be calculated. The relevant parts of the spectrum taken at 2 cm, with absorbers, are plotted in Fig. 1.

The efficiency of the system at 2 cm distance from the detector, for the weak gamma-ray lines, was measured by preparing an extended calibrated source of ^{137}Cs of about the same shape as the Ho metal plate. The results of this calibration agree within 10% with measurements made using a calibrated point source.

3. RESULTS AND DISCUSSION

Preliminary runs made with a few grams of oxide showed two gamma-ray lines at 689.3 and 762.4 keV which were followed for two consecutive half-lives at each of two different geometries. The half-life of their intensities was measured to be 37 ± 5 min agreeing with the 38 min half-life of $^{164}Ho^m$. The ratio of the intensity of the 762.4 keV line to that of the 689.3 keV line (0.9 ± 0.1) and the energy values agree within the experimental error with the work of Schult et al [4]. These two gamma-rays were thus assumed to result from the electron-capture transition from the ground state of ^{164}Ho to the 761.7 keV $4\ 2^+$ level of ^{164}Dy. The partial half-life for this transition was calculated to be 0.95×10^8 sec. Taking 360 keV as the decay energy of the transition, a log ft value of 8.0 was obtained.

Corrections of about 60% for Cd-Cu attenuation of the high energy lines, of about 50% for self-absorption of the 91.6 keV γ-rays, of about 10% for the dead time and 7% for the graphite absorption of the 91.6 keV line, were applied to calculate the ratio of this transition to the 91.6 keV transition in ^{164}Er which would be the least self-absorbed and for which the branching ratio of (2.4 ± 0.1)% was reasonably well known [12, 13].

An uncertainty of 40% has been attributed to the final result mainly because the ratio of production of the two isomers is unknown in the present experimental conditions. Other uncertainties are the value of 38 min for the half-life of the metastable isomer used in the calculation to transform the two counting rates to the same time basis, which could contribute 15%

uncertainty to the calculations of the branching ratio, and an uncertainty of about 10% in the value of 27 min for the half-life of the ground state of ^{164}Ho. The time constant for attainment of equilibrium, was calculated to be between 1 and 2 hours. Since the target had been bombarded for one hour, and half an hour elapsed before the counting started, it was estimated that the assumption that an equilibrium mixture of isomers was used, could contribute an uncertainty of 30% in the determination of the branching ratio. This is the most serious uncertainty in the whole measurement and in itself would justify neglecting all but two of the other corrections. But since it might turn out that an equilibrium mixture of the two isomers could have been present at the time the measurements were performed, it was felt that other corrections, some amounting to less than 30%, should be applied.

The data were also inspected for a pair of gamma-ray lines of about equal intensity, differing by 92 keV in the regions of 770 and 860 keV. A lower limit of 7.6 could be set for the log ft value of a possible transition to the $2'^{+}$ level of ^{164}Er.

The results obtained can be explained in the light of recent theories of the structure of gamma-vibrational states. Bès [9] and Soloviev [10] have attempted to explain the structure of 2^{+} gamma-vibrational states of deformed nuclei in terms of the quadrupole-force coupling of the individual motions of 2^{+} two-quasi-particle states. The form of the wave function of collective states is a linear expansion in terms of 2^{+} quasi-particle-pair states but only a few of these states dominate th structure of the collective state.

The ground state configuration of ^{164}Ho, like ^{162}Ho, is p|523|↑ n|523|↓ to give $I^{\pi}K = 1^{+}\ 1$ in accord with the Gallagher-Moszkowski [17] strong coupling rules. This configuration is suggested by the odd mass neighbours in which the 67^{th} proton in the ground state of 161, 163, 165 and ^{167}Ho occur in the $7/2^{-}$ |523| orbital, and the 97^{th} neutron in the ground state of ^{161}Gd, ^{163}Dy, ^{165}Er, and ^{167}Yb are known to be in the $5/2^{-}$ |523|↓ state [18].

The transition found in the present experiment would be a transition p|523|↑ → n|521|↓ because of the predicted two-quasi-particle configuration of the gamma-vibrational state.

In terms of two-quasi-particle states, the structure of the $I^{\pi}K = 2^{+}2$ gamma-vibrational states of Dy and Er are very similar indeed. According to Bès [9] the only configurations that contribute significantly to the gamma-vibrational states of Dy and Er with more than 10% or which have a proton or neutron orbital identical with the ground-state of ^{164}Ho, or both, are listed in table 1. Thus according to this microscopic theory, a sizeable admixture of 26% and 21% of the two-quasi-particle state n|523|↓ |521|↓ is present in Dy and Er respectively. This two-quasi-particle state is effectively the only one that plays a part in the transition, because F-forbidden transitions (more than one quasi-particle being involved in the transition) are strictly forbidden, and the p|523|↑ |521|↓ state admixture is too small. This transition would be allowed according to all selection rules except for $\Delta\Lambda = 2$ which would make it allowed hindered.[19]

The log ft value of 8.0 for the transition to the $2'^{+}$ level of ^{164}Dy is compatible with an allowed hindered transition. Since the two $2'^{+}$ levels have very similar configurations, 7.6 for the lower limit of the log ft value of the Er transition is also consistent with the theory.

A similar transition with log ft $\cong$ 8 might be observed in the decay of ^{162}Ho to the 890 keV level in ^{162}Dy, since according to Bès an admixture of 21% of the two-quasi-neutron state |523|↓ |521|↓ is present in that level.

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ACKNOWLEDGEMENTS

It is a pleasure to express our gratitude to professor R. van Lieshout for helpful discussions and critical reading of the manuscript. We want to thank very much the "Comissão Nacional de Energia Nuclear" of Brazil for the funds contributed. Thanks are also due to "Conselho Nacional de Pesquisas".

TABLE 1: Contribution (in %) of selected quasi-particle-pair states to the gamma-vibrational 2^+ states of ^{164}Dy and ^{164}Er.

	^{164}Dy	^{164}Er
n|523|↓ |521|↓	26	21
n|521|↑ |521|↓	21	25
p|411|↑ |411|↓	17	14
p|413|↓ |411|↓	12	10
p|523|↑ |521|↓	< 0.5	0.5

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