Electric-dipole transitions in ^{165}Er*

WANG Shi-Tao(王世陶)[1,2] ZHOU Xiao-Hong(周小红)[1,2;1)] ZHANG Yu-Hu(张玉虎)[1,2]
ZHENG Yong(郑勇)[1] LIU Min-Liang(柳敏良)[1] MA Fei(马飞)[1,2] HU Jun(胡钧)[1,2]
CHEN Liang(陈亮)[1,2] ZHANG Xin(张昕)[1,2] ZHANG Ning-Tao(张宁涛)[1,2]
ZHU Li-Hua(竺礼华)[3] WU Xiao-Guang(吴晓光)[3] LI Guang-Sheng(李广生)[3]

1 (Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China)
2 (Graduate University of Chinese Academy of Sciences, Beijing 100049, China)
3 (China Institute of Atomic Energy, Beijing 102413, China)

Abstract High-spin states of ^{165}Er were studied using the ^{160}Gd(^{9}Be, 4n)reaction at beam energies of 42 and 45 MeV. The previously known bands based on the $\nu 5/2^-[523]$ and $\nu 5/2^+[642]$ configurations have been extended to high-spin states. Electric-dipole transitions linking these two opposite parity bands were observed. Relatively large B(E1) values have been extracted experimentally and were attributed to octupole softness.

Key words fusion-evaporation reaction, high-spin state, electric-dipole transition, octupole softness

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1 Introduction

Generally, low-energy electric-dipole (E1) transitions observed in nuclei are strongly hindered and the major part of the E1 transitions is shifted to the giant dipole resonance (GDR) of energy higher than 10 MeV[1—3]. The low-energy B(E1) values with single-particle estimation are typically 10^{-6} in Weisskopf units. In some cases, E1 transitions observed between two rotational bands with opposite parity are enhanced as compared to single-particle expectations[3—9]. These enhanced E1 transitions have B(E1) values of the order of or larger than 10^{-4} e^{2}fm^2. The relatively strong E1 transitions observed in nuclei are supposed to be related to the softness against octupole deformations[1, 2]. In the presence of an octupole deformation an electric-dipole moment may arise in the intrinsic frame due to a shift between the center of mass of the nucleus and its center of charge. Such a dipole moment manifests itself by enhanced E1 transitions between members of opposite parity rotational bands[2, 10].

It is well known that nuclei in the light Ra-Th (Z=88, N=136) and heavy Ba-Sm (Z=56, N=88) regions, where alternate-parity bands linked by enhanced E1 transitions were observed, have octupole deformation[11]. On the other hand, strong E1 transitions between two rotational bands of odd-A rare-earth nuclei that are well quadrupole-deformed and usually supposed to be stable against octupole deformations were also reported[6]. In this region, no strongly collective octupole vibrational states were observed. Because there is no other obvious reason which may lead to an enhancement of E1 strengths, a contribution from possible octupole softness is invoked to the E1 strengths. E1 transitions connecting the $5/2^-[523]$ and $5/2^+[642]$ bands have been observed in ^{161}Dy[8], ^{163}Er[6, 12] and ^{167}Yb[6]. In the present work, several enhanced E1 transitions between the $5/2^-[523]$ and $5/2^+[642]$ bands in ^{165}Er were observed and B(E1) values were extracted.

2 Experimental procedure and results

High-spin states of ^{165}Er were produced using the reaction ^{160}Gd(^{9}Be, 4n) with 42 and 45 MeV ^{9}Be beams, provided by the HI-13 Tandem Accelerator at China Institute of Atomic Energy (CIAE) in Bei-

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1) E-mail: zxh@impcas.ac.cn

jing. The target was a self-supporting ^{160}Gd metallic foil enriched to 98.1% with a thickness of 2.1 mg/cm^2. The γ-γ coincidence events were collected with an array of thirteen Compton-suppressed HPGe detectors, and a total of 80×10^6 double or higher-fold events have been recorded for off-line analysis.

Before this experiment, the rotational bands in ^{165}Er based on the $5/2^+[642]$ and the $5/2^-[523]$ neutron single-particle orbits were known up to $25/2^+$ and $11/2^-$ states[13], respectively. In this paper, considerable extensions have been made to these two bands. The bands based on the configurations $5/2^+[642]$ and $5/2^-[523]$ were extended to $49/2^+$ and $45/2^-$, respectively. Moreover, several electric-dipole transitions have been observed between the $5/2^-[523]$ and $5/2^+[642]$ bands. The level scheme of ^{165}Er is shown in Fig. 1, and typical coincidence spectra are shown in Fig. 2.

The $5/2^-[523]$ band is the ground-state rotational band populated weakly. The strongly populated rotational band of $5/2^+[642]$ originating from the $i_{13/2}$ configuration, with the opposite parity against the ground-state band, becomes yrast immediately after the angular momentum is increased by a few $\hbar$. These two rotational bands of opposite parity coexist along the yrast line over a relatively wide range of rotational frequencies. The sequences of the $5/2^-[523]$ band decay to the $5/2^+[642]$ band through stretched E1 transitions.

The B(E1) values for the observed E1 transitions between the bands built on the $5/2^-[523]$ and $5/2^+[642]$ configurations can be extracted using the following expression[5]:

$$B(\mathrm{E1}) = 7.63\times10^{-4}Q_\mathrm{t}^2\langle IK20\,|\,I-2K\rangle^2\times \frac{1}{\lambda}\frac{E_\gamma^5(\mathrm{E2})}{E_\gamma^3(\mathrm{E1})}(\mathrm{e^2fm^2}), \tag{1}$$

where λ is the branching ratio $I_\gamma(\mathrm{E2})/I_\gamma(\mathrm{E1})$, and E_γ is measured in MeV and Q_t in units of b. The branching ratios were obtained by setting gates above the decaying levels and the data were not corrected for angular correlation effects. Because no lifetimes were measured, the value of Q_t^2=50 b^2 was assumed by systematics in this region[6]. The B(E1) values obtained in the present work are shown in Table 1.

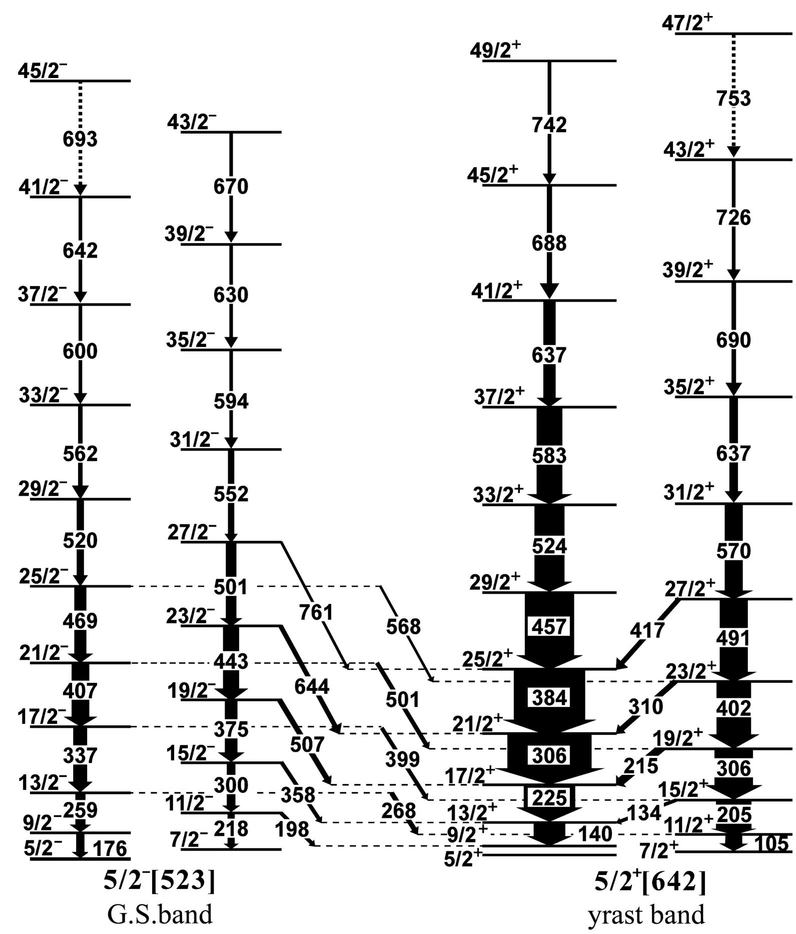

Fig. 1. Partial level scheme of ^{165}Er.

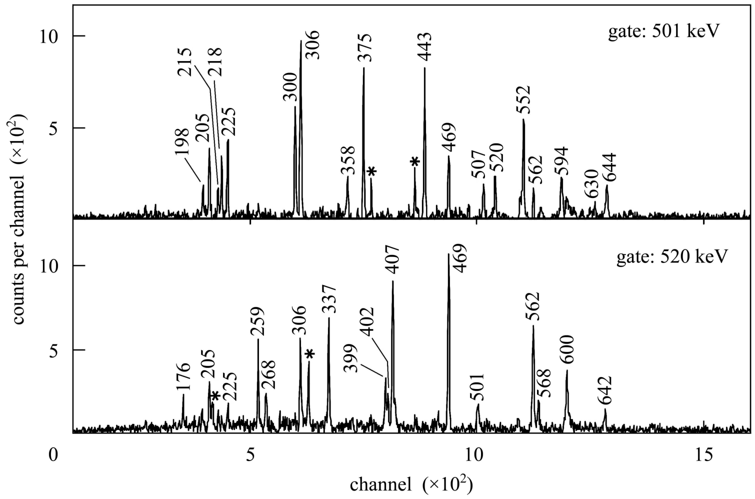

Fig. 2. Coincidence spectra gated on the 501 and 520 keV γ rays. The asterisks indicate contaminations.

Table 1. Experimental λ, B(E1) and R(E1) values obtained in the present work.

E_γ/keV	$I_i^\pi/\hbar$	$I_f^\pi/\hbar$	$\lambda^{a)}$	B(E1)/(10^{-4} e^{2}fm^2)	R(E1)/10^{-2}
197.8	$11/2^-$	$9/2^+$	2.32(27)	1.80(22)	1.60(10)
267.6	$13/2^-$	$11/2^+$	2.19(20)	2.30(22)	1.73(8)
357.5	$15/2^-$	$13/2^+$	2.49(33)	2.03(27)	1.58(10)
399.3	$17/2^-$	$15/2^+$	3.42(32)	2.06(20)	1.57(8)
507.4	$19/2^-$	$17/2^+$	2.82(48)	2.26(38)	1.62(14)
501.1	$21/2^-$	$19/2^+$	4.72(55)	2.17(26)	1.57(9)
643.5	$23/2^-$	$21/2^+$	3.24(50)	2.36(37)	1.63(13)
567.8	$25/2^-$	$23/2^+$	6.48(118)	2.37(43)	1.62(15)
761.0	$27/2^-$	$25/2^+$	4.38(88)	2.09(42)	1.52(15)

a) Branching ratio: I_γ(E2)/I_γ(E1), I_γ(E2) and I_γ(E1) are the relative γ intensities of E2 and E1 transitions depopulating the same level, respectively.

3 Discussion

Hagemann et al.[6] calculated the B(E1) values in odd-A rare-earth nuclei using a model in which one quasiparticle was coupled to an axially symmetric rotor. It was found that the obtained B(E1) values in the model turned out to be too small as compared with experimental data. Since it was impossible to obtain the measured magnitudes of B(E1) values with the standard E1 transition operator, the following E1 transition operator, taking into account the effect of octupole softness, was proposed[6].

$$O(\mathrm{E1},\nu)=e_{\mathrm{eff}}(\mathrm{E1})rY_{1\nu}+eb_\nu r^3Y_{3\nu}\,. \tag{2}$$

The second term on the right hand side of Eq. (2) caused the enhancement of the E1 strength. If the parameters b_0 and $b_{\pm1}$ were properly determined, a relatively satisfactory agreement between experiment and theory could be obtained.

If the Alaga rule works, the B(E1) value can be expressed using the following equation[14]:

$$B(\mathrm{E1})=\mathrm{const.}\langle I_iK_i1K_f-K_i\,|\,I_fK_f\rangle^2\,. \tag{3}$$

However, the observed B(E1) values in ^{177}Hf are not in accordance with the Alaga rule[14] and exhibit major deviations from constancy. They are seen to be consistent with the following equation:

$$B(\mathrm{E1})=\left\{M_1+M_2[I_f(I_f+1)-I_i(I_i+1)]\right\}^2\times\langle I_iK_i1K_f-K_i\,|\,I_fK_f\rangle^2\,. \tag{4}$$

Then the R(E1) values defined below would be a linear function of $I_f(I_f+1)-I_i(I_i+1)$ and the magnitude of the M_2 term implies the degree of the deviations of the R(E1) values from constancy.

$$R(\mathrm{E1})=\left[\frac{B(\mathrm{E1})/B_{\mathrm{W.U.}}(\mathrm{E1})}{\langle I_iK_i1K_f-K_i\,|\,I_fK_f\rangle^2}\right]^{1/2}=M_1+M_2[I_f(I_f+1)-I_i(I_i+1)], \tag{5}$$

where $B_{\mathrm{W.U.}}$(E1) is the Weisskopf units with the value of 1.94 e^{2}fm^2 in ^{165}Er.

Bohr and Mottelson indicated that the angular momentum dependent term M_2 may be attributed to the coriolis interaction. The probable contributions from octupole deformation were also indicated.

Recent calculations[1, 2, 6] indicate that, although all important matrix elements of the coriolis coupling have been taken into account, the calculated B(E1) values turn out to be too small compared with the experimental results and the angular momentum dependence of the calculated B(E1) values does not agree with that of the measured ones. Therefore, the octupole softness, the effect of which has already been stressed by Bohr and Mottelson, may be almost the only left-over source which could be imagined to provide an appreciable amount of the E1 transition strength and to obtain an agreement between the angular momentum dependence of the calculated B(E1) values and that of the observed ones.

The R(E1) values of ^{165}Er derived from this experiment are shown in Table 1 and Fig. 3, from which we can see that the R(E1) values are nearly constant and independent to $I_f(I_f+1)-I_i(I_i+1)$. It is noted that the extracted R(E1) values in ^{163}Er[9] are a decreasing function of $I_f(I_f+1)-I_i(I_i+1)$, which is different from the situation observed in ^{165}Er. Hamamoto[2] pointed out that the b_ν values in Eq. (2), which could produce the dependence of the R(E1) (also the B(E1)) values on the variable $I_f(I_f+1)-I_i(I_i+1)$, depended on the nuclei and were sensitive to the pair of the bands. So, it is easy to understand the difference in the angular momentum dependence of the R(E1) values between ^{165}Er and ^{163}Er. The unique b_ν values in ^{165}Er different from those in other nuclei can be obtained by fitting the B(E1) values extracted from the experimental data[1, 2, 6].

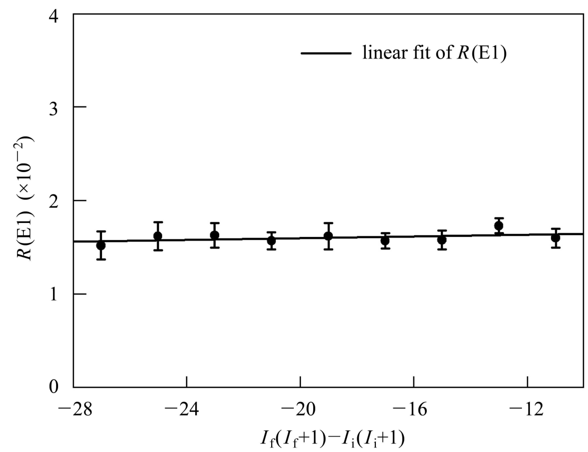

Fig. 3. R(E1) values from the $5/2^-[523]$ to the $5/2^+[642]$ band in ^{165}Er.

In summary, high-spin states of ^{165}Er have been studied via the ^{160}Gd(^{9}Be, 4n)^{165}Er fusion-evaporation reaction. Two bands based on the configurations $5/2^+[642]$ and $5/2^-[523]$, between which enhanced E1 transitions were observed, have been extended to $49/2^+$ and $45/2^-$, respectively. The B(E1) values in ^{165}Er have been extracted experimentally. The enhancement of the B(E1) values and the angular momentum dependence of the R(E1) values could be explained by taking into account the effect of octupole softness.

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