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Cluster structure and deformed bands in the ^{38}Ar nucleus

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Abstract

The structure of the ^{38}Ar nucleus is investigated by the $^{34}\mathrm{S}+\alpha$ orthogonality condition model (OCM). The energy spectra, electromagnetic transitions and α spectroscopic factors are calculated. The excited states can be grouped into several bands according to the leading configurations of their wave functions, and the structures of the bands are discussed. The first excited $K^\pi = 0^+$ band is found to be predominantly $^{34}\mathrm{S}+\alpha$ cluster states. It is also shown that the observed energies and $E2$ transitions of the band are well reproduced by the model. The existence of a negative-parity doublet band of the band is also predicted. The strength of the α-cluster states is shown to be spread over several levels due to mixing of shell-model states and various α-cluster states.

Keywords: ^{38}Ar; Cluster model; Superdeformed band; Transitions; Spectroscopic factors

1. Introduction

The investigation of superdeformed (SD) rotational bands in ^{36}Ar–^{48}Cr nuclei has received considerable attention and the fine spectroscopic measurements have been accumulated: rotational spectra extended up to the total angular momentum $J^\pi = 16^+$ and strong enhancements of $E2$ transitions [1–12]. These collective aspects are particularly interesting subjects for nuclear

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structure studies. They are often investigated by the multiparticle–multihole excitations in the large-scale shell-model calculations [5,13], cranked Skyrme–Hartree–Fock calculations [14–18], cluster models [19–22] and the antisymmetrized molecular dynamics calculations [23,24]. These various types of approaches would be used to provide complementary views of the SD bands.

Moreover, these nuclei are known to show various clustering aspects as well. The relation between the origin of SD and clustering has been discussed for the ^{32}S nucleus with the ^{16}O + ^{16}O cluster structure [25–27] and for the ^{28}Si nucleus with the ^{16}O + ^{12}C cluster structure [28]. We have performed α-cluster model calculations for ^{36}Ar–^{48}Cr nuclei [19,20,29–36]. It was shown that the α-cluster structure is a stable feature in these nuclei and also the α–nh weak coupling pictures systematically persist in this region. The close relation between the SD bands and α-clustering was well studied in the ^{36}Ar and ^{40}Ca nuclei. In ^{36}Ar, the SD is assigned to a $4p$–$8h$ band built on the 0_2^+(4.329 MeV) state. On the other hand, the SD band in ^{40}Ca is identified with the band built on the 0_3^+(5.213 MeV) and is an $8p$–$8h$ configuration. The rotational structure built on the 0_2^+(3.352 MeV) is interpreted as a less deformed $4p$–$4h$ configuration. So it is very interesting to study how the α-clustering and the deformation properties change according to moving from ^{36}Ar to ^{40}Ca.

The nucleus ^{38}Ar is the adjacent transitional nucleus and is much less understood than the ^{36}Ar and ^{40}Ca nuclei. The nucleus ^{38}Ar was not thoroughly studied yet due to the death of experimental information. Later, excited states in ^{38}Ar were investigated by the fusion–evaporation reaction [5,6] and the three kinds of deformed rotational bands in positive-parity states were classified. Therefore, in order to clarify the α-cluster structure for nuclei in the range between ^{36}Ar and ^{40}Ca and also the relation with the superdeformation, we will apply a $^{34}\mathrm{S} + \alpha$ orthogonality condition model (OCM) for the ^{38}Ar nucleus. This model is a sort of unified model, because it can describe simultaneously cluster states and important shell-model states. This model approach is expected to provide intuitive and unique insights into the deformed bands properties in ^{38}Ar. In the positive-parity states, we investigate to what extent the present model can explain the energy spectra and $E2$ transitions of the three deformed bands. We also analyze the α-spectroscopic properties which are very helpful in making assignments of α-cluster states.

2. $^{34}\mathrm{S} + \alpha$ orthogonality condition model

The model space is spanned by the product wave functions of ^{34}S and α clusters:

$$\Phi_J^{KIl} = \sqrt{4!34!/38!}\mathcal{A}\left\{\phi(\alpha)\left[\phi_{KI}\left(^{34}\mathrm{S}\right), Y_l(\hat{\mathbf{r}})\right]_J R_{Nl}(r)\right\}, \tag{1}$$

where $\mathcal{A}$ is the antisymmetrizer between the clusters and $R_{Nl}(r)$ is a radial harmonic oscillator function with N oscillator quanta of the relative motion. The angular momenta of ^{34}S and the relative motion, I and l, respectively, are coupled to the total angular momentum J. The antisymmetrized internal wave functions $\phi(\alpha)$ and $\phi_{KI}(^{34}\mathrm{S})$ are assumed to be $(0s)^4$ and $(sd)^{-6}$ with the SU(3) symmetry $(\lambda, \mu) = (2, 8)$ configurations, respectively. We adopt a common oscillator constant $a = 0.294\ \mathrm{fm}^{-2}$ for all cluster. The core wave function $\phi_{KI}(^{34}\mathrm{S})$ is generated from the intrinsic wave function of minimum weight as

$$\phi_{KI}\left(^{34}\mathrm{S}\right) = \frac{8I+1}{8\pi^2 a((28)KI)} \int d\Omega\, \mathcal{D}_{MK}^{I}(\Omega)^* \phi_\Omega\left(^{34}\mathrm{S}\right), \tag{2}$$

where $a((28)KI)$ is a normalization coefficient. In the angular momentum projection, $\phi_\Omega(^{34}\mathrm{S})$ is the intrinsic function rotated through the Euler angle Ω.