Shell-model calculation of $^{51}$V using pairing-plus-surface-tensor-interaction

D. BANERJEE and L K CHAKRABORTY*
Department of Physics, Calcutta University, Science College, 92 A. P. C. Road, Calcutta 700 009
*Department of Physics, Maharaja Manindra Chandra College, Calcutta 700 003

MS received 9 January 1978; revised 26 April 1978

Abstract. Employing $^{48}$Ca as the core, the structure of $^{51}$V is studied in the framework of a conventional shell-model. A pairing-plus-surface-tensor-interaction is used as the effective two-body interaction. Besides all configurations arising from $1f_{7/2}$ and $2p_{3/2}$ single-particle orbits, configurations of the form $(1f_{7/2})^{n_1} (1f_{5/2})^{n_2}$ where $n_1 + n_2 = 3$ (the number of extracore protons) and $n_2 = 1, 2$ are also considered. Low-lying energy levels are calculated and a satisfactory agreement with the experimental values is obtained. Our calculated density of states is higher than that reported previously. We also present the $B(E2)$ values for transitions between low-lying levels and the spectroscopic factors for the $^{48}$Ti($^3$He, d) $^{51}$V reaction. The dependence of the interaction parameters on the mass number of the core nucleus is also studied.

Keywords. Nuclear structure $^{51}$V; calculated levels; spectroscopic factors; $B(E2)$ values; shell-model method; pairing-plus-surface-tensor-interaction.

1. Introduction

$^{51}$V is one of the well studied nuclei in the $f-p$ shell. A lot of experimental as well as theoretical work has been done in the past. Theoretically $^{51}$V has been described mostly from the shell-model point of view using different sets of effective two-body matrix elements. McCullen et al (1964) described $^{51}$V assuming a pure $(1f_{7/2})^3$ configuration for the valence protons outside the closed core, $^{48}$Ca. Such calculations have several defects. They do not predict enough levels at excitation energies greater than 2 MeV. This is to be expected since one would expect a mixing of configurations at high excitation energies, tending to depress the calculated energy levels. The pure-configuration model also fails to account for the enhanced $B(E2)$ transition rates. In view of the above discrepancies, Scholz and Melik (1966a, b, 1967) studied $^{51}$V using strong Coriolis-coupling model. These authors succeeded in explaining the enhanced transition rates, but their reproduction of energy levels was not good. The calculated density of states in particular, between 3·0 and 5·0 MeV was too low. Though there are a lot of discrepancies in pure $(1f_{7/2})^3$ configuration calculation, there is no reason to believe that such discrepancies cannot be accounted for by a mixed configuration calculation. In fact, Lips and McEllistrem (1970) considered mixing states with proton configurations $(1f''_{7/2} 2p_{3/2})$, $(1f''_{7/2} 1f_{5/2})$ and $(1f''_{7/2})$ and explained satisfactorily the nucleon transfer data, $E2$ transition probabi-
ties and the energy spectrum. The two-body matrix elements involving $1f_{5/2}$ protons were obtained from the modified surface-delta residual interaction (MSDI). The two-body matrix elements for other configurations were determined by empirical method. The entire calculation was also carried out using the Kuo-Brown's (1968) reaction matrix elements for the two-body interactions involving $1f_{5/2}$ protons. Lips and McEllistrem (1970) calculated the $E2$-transition rates using an effective charge $1.6e$ for each of the three protons outside the core. The low-lying levels were well reproduced by using a mixture of empirical and MSDI matrix elements. Lips and McEllistrem have not given the results of their calculation for energy levels above 4 MeV. Experimentally, a lot of energy levels have been observed above 4 MeV and spins have also been tentatively assigned to them. Rustgi et al. (1971) performed an extended study of $^{51}$V within the framework of spherical shell-model considering all $1f-2p$ configurations for the extracore protons. In one type, the Lips-McEllistrem matrix elements were used for the configurations used by them and the Kuo-Brown matrix elements for the remaining configurations. They have also given their results upto 4.4 MeV only. The results were inferior to both of those obtained with only Kuo-Brown matrix elements and to a limited space calculations of Lips and McEllistrem. Thus the inclusion of higher configurations which were not considered by Lips and McEllistrem could not produce better results. This is expected because the derived two-body matrix elements depend on the configurations used in their determination. Moreover, it is difficult to justify the shell-model calculation with the combination of matrix elements determined from different interactions. The energy levels calculated with Kuo-Brown matrix elements lie higher than the observed ones. This is because there are uncertainties in the $T=1$ part of the Kuo-Brown interaction. This is clear from the work of Bhatt and McGrory (1971) who used the $T=1$ part of the Kuo-Brown interaction in a study of the structure of the calcium isotopes. The quality of the agreement was not good. In particular, the ground state energies were poorly reproduced. It is interesting to note that the results of Rustgi et al. (1971) for the electromagnetic properties are satisfactory though the energy levels are not well reproduced. The calculated spectroscopic factors differ considerably with the calculations of Lips and McEllistrem as well as with the experimental values for the second (3/2$^-$) and (5/2$^-$) states.

In this paper we report the spherical shell-model study of $^{51}$V using a pairing plus-surface-tensor-interaction (PSTI). This interaction consists of the usual pairing force plus a tensor force which acts at the nuclear surface only. This interaction is originally proposed for the study of the calcium isotopes (Banerjee and Richert 1972). The calcium isotopes ($A=42-48$) are successfully described by this interaction (Banerjee and Oberlechner 1973). This indicates that $T=1$ part of the PSTI is good. We have also studied $^{44}$Ti with the PSTI and the results are found satisfactory (Banerjee 1974). Previous studies of the calcium isotopes and $^{44}$Ti with PSTI indicate that the tensor part of this effective two-body interaction has the effect of pushing down the energy levels. As a result, the calculated density of low-lying energy levels is increased. Thus we hope that one of the drawbacks of previous shell-model calculations for $^{51}$V namely, the low density of calculated energy levels, is removed to a great extent using PSTI as the effective two-body interaction. Also this study will reveal the suitability of PSTI as the effective two-body interaction in the $f-p$ shell region.

In section 2 we describe the details of our shell-model calculations and in section 3