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Evidence for core excitation in single-particle states of ^{19}Na

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Abstract

We present an experimental study of ^{19}Na states in the excitation energy range between 2 and 3 MeV. The presence of ^{19}Na single-particle levels at these energies was first predicted by a microscopic cluster model and then experimentally confirmed by measuring the elastic and inelastic scattering of a 66 MeV ^{18}Ne radioactive beam on a $(CH_2)_n$ target. The H(^{18}Ne, p)^{18}Ne(g.s.) and H(^{18}Ne, p')^{18}Ne*(2^+, 1.887 MeV) cross sections have been obtained in the laboratory angular range $\theta_{lab} = 6.1°–18.4°$ and analyzed by using the R-matrix method. Two new states in ^{19}Na have been observed at centre-of-mass energies $E_{c.m.} = 2.78 \pm 0.01$ MeV and 3.09 ± 0.05 MeV. Both resonances exhibit large widths in the ^{18}Ne(2^+) + p channel, and low branching ratios into the elastic channel. The reduced proton widths confirm the single-particle nature of these states, with a ^{18}Ne(2^+) + p structure.
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1. Introduction

The existence of single-particle states [1] is well established in many stable nuclei. A single-particle state can be considered as an inert core (usually in its ground state) surrounded by a valence nucleon. The main characteristic of such a state is a large reduced width, close to the Wigner limit. The concept of single-particle states can be extended in two directions: to nuclei near or beyond the drip lines, and to specific states where the core nucleus is in an excited state.

The aim of the present Letter is to investigate the ^{19}Na spectrum above 2 MeV by inverse elastic and inelastic scattering of a ^{18}Ne radioactive beam on a proton target. In a previous experiment [2], we considered the low-energy region and found evidence for a new $1/2^+$ level ($\ell = 0$) at $E_{c.m.} = 1.06$ MeV. This state is characterized by a strong Coulomb shift, consistent with a large reduced width. Its interpretation as a ^{18}Ne(0^+) + p single-particle state was confirmed in subsequent experiments [3,4].

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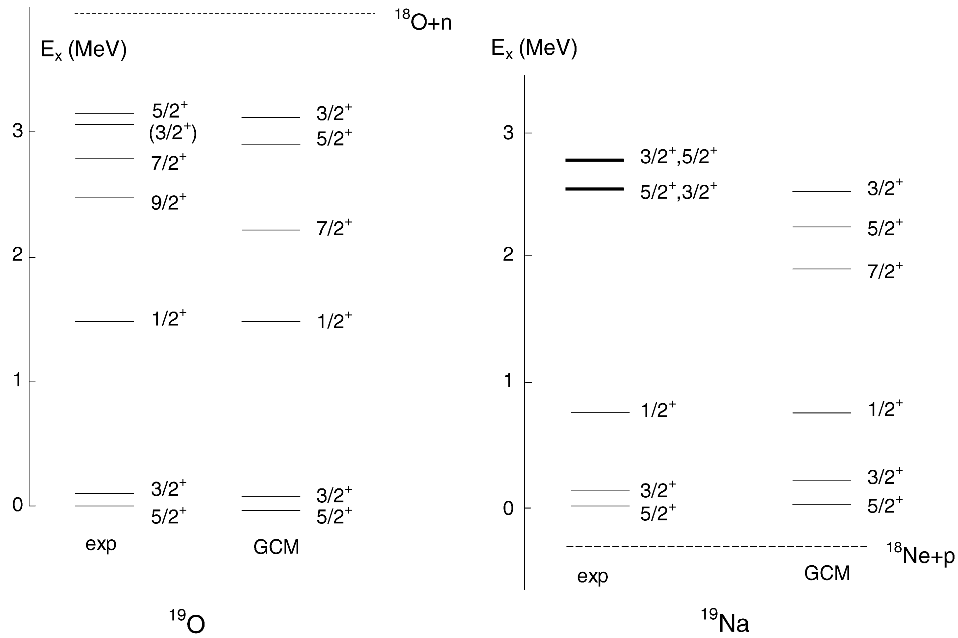

Fig. 1. GCM and experimental ^{19}O and ^{19}Na spectra. The ^{19}Na states in bold were observed in the present experiment. The particle thresholds are shown as dashed lines.

In this work, we have investigated simultaneously the $^{18}\mathrm{Ne}+p$ elastic and inelastic scattering, to search for mirror states of ^{19}O. The mirror ^{19}O nucleus is stable against neutron decay ($\tau_{1/2}=27s$) and has been studied in various experiments and theoretical models (see for example Refs. [5,6].) Calculations based on a microscopic cluster model suggest that states with large $^{18}\mathrm{O}(2^+)+n$ or $^{18}\mathrm{Ne}(2^+)+p$ components are expected above 2 MeV excitation energy. Such states cannot be easily observed in elastic scattering, but are expected to show up in the H(^{18}Ne, p')^{18}Ne* inelastic cross section, where ^{18}Ne is in its first excited state (1.887 MeV, 2^+). The existence of core excitations in single-particle states is predicted by theory in several nuclei, and it is in that context that the present work was undertaken.

2. Microscopic calculation

Before running the experiment we have performed a preliminary calculation using a microscopic cluster model [7], based on the generator coordinate method (GCM) [8]. In this model, all nucleons are taken into account, and the Hamiltonian is given by

$$H=\sum_{i=1}^{19}T_i+\sum_{i>j=1}^{19}V_{ij}, \tag{1}$$

where T_i is the kinetic energy of nucleon i, and V_{ij} is a nucleon–nucleon interaction, taken here as the Volkov V2 force [9].

The GCM wave functions of ^{19}Na are factorized into ^{18}Ne and p internal wave functions as

$$\psi=\sum_k \mathcal{A}\phi_{18}^k\phi_p g_k(\rho), \tag{2}$$

Table 1
GCM energies and widths of ^{19}Na resonances. Total widths are given in keV, and dimensionless reduced widths (at $a=5$ fm) in %. Angular momenta in the elastic and inelastic channels are denoted by ℓ_0 and ℓ_2, respectively. The notation x^n stands for $x\times10^n$

J^π	$E_{\mathrm{c.m.}}$ (MeV)	ℓ_0	ℓ_2	Γ_0	Γ_2	θ_0^2	θ_2^2
$1/2^+$	1.06	0	2	130	–	30	2.6
$7/2^+$	2.18	4	2	1.5^{-5}	8.9^{-5}	1.0^{-3}	5.4
$5/2^+$	2.52	2	0	1.5	19	0.3	50
$3/2^+$	2.81	2	0	2.0	79	0.3	31

where k labels the channels, $\mathcal{A}$ is the antisymmetrization operator, ϕ_{18}^k are shell-model wave functions of ^{18}O/^{18}Ne and g_k are radial functions depending on the relative coordinate ρ. All sd-shell states are included in the ^{18}O/^{18}Ne wave functions, in particular the 0^+ ground state, and the 2^+ first excited state (see Ref. [10] for details). The angular momentum projection is performed using standard methods [7]. This model has been used to investigate many nuclei and reactions (see for example Ref. [11]), and is well adapted to exotic nuclei with low level densities.

In Fig. 1, we present the ^{19}O and ^{19}Na spectra obtained from the GCM calculations. In both systems, the admixture parameter M of the Volkov force has been determined from the experimental $1/2^+$ energy. All other energies were obtained without any fitting. The low-lying part of both spectra is remarkably well reproduced by the GCM. The proton widths in the $^{18}\mathrm{Ne}(0^+)+p$ and $^{18}\mathrm{Ne}(2^+)+p$ channels (referred to by the indices “0” and “2”, respectively) are given in Table 1, as are the angular momenta ℓ_0 and ℓ_2. Since the 2^+ excitation energy is slightly underestimated by the GCM (1.54 MeV whereas experiment gives 1.88 MeV), we have corrected the Γ_2 values to account for the experimental threshold.

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