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Spectroscopy of the unbound nucleus ^{18}Na

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The unbound nucleus ^{18}Na, the intermediate nucleus in the two-proton radioactivity of ^{19}Mg, is studied through the resonant elastic scattering ^{17}Ne(p,^{17}Ne)p. The spectroscopic information obtained in this experiment is discussed and put in perspective with previous measurements and the structure of the mirror nucleus ^{18}N.

1. Introduction

Near the proton drip-line, where nuclear binding energies are almost zero, the pairing force could play a more important role than in stable nuclei. Sometimes it leads to a situation where a drip-line nucleus is bound with respect to single-proton decay but unbound to two-proton radioactivity.[1] Then this phenomenon can proceed:

(i) either through simultaneous emission (^{2}He emission) where the two protons form a quasiparticle due to pairing force that facilitates the penetration of the Coulomb barrier;

(ii) or by sequential emission through an intermediate state (or eventually the tail of a resonant state) that can be described by genuine three-particle decay.

Very few intermediate nuclei $^{A-1}_{Z-1}$X are accessible experimentally. Among them,

^{18}Na, the intermediate nucleus in the ^{19}Mg two-proton decay, was studied by stripping reaction[2,3] but its ground state and first excited states were not clearly identified. In this letter, new results concerning ^{18}Na obtained from the resonant elastic scattering experiment ^{17}Ne(p,^{17}Ne)p are presented.

2. Experimental Set-Up and Analysis

The elastic scattering reaction^{17}Ne(p,^{17}Ne)p was measured in inverse kinematics with a ^{17}Ne beam at 4 A.MeV produced by the Spiral facility at GANIL and an intensity of 10^4 pps. It was impinging on a 150μm thick polypropylen (CH_2) target where the beam was stopped. With this method, the full excitation function up to 4 MeV in the center-of-mass framework was obtained all at once (for details on the method see [4]). The outcoming protons were detected with two ΔE-E telescopes

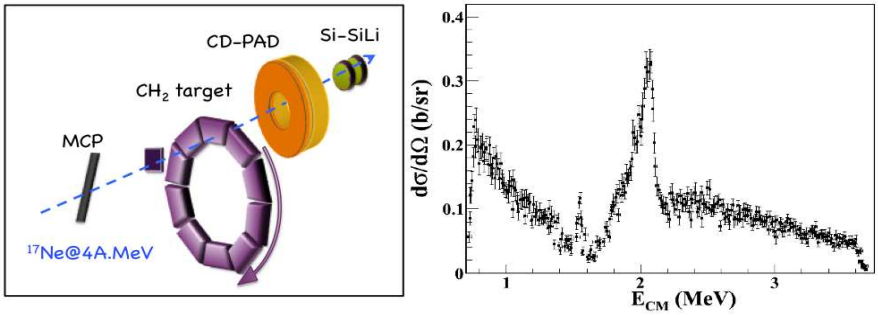


Fig. 1. Left: Experimental set-up for the study of ^{17}Ne(p,^{17}Ne)p resonant elastic scattering (see text for description). Right : Excitation function in the center -of-mass framework corrected from ^{12}C background and residual βp background from ^{17}Ne decay.

(see Fig. 1) : (i) the first one located at zero degree is composed of a 150μm thick Silicon detector and a 6 mm Silicon-Lithium detector which was cooled down to -20^{o}C. It was covering from -2 to 2 degrees with a total resolution of 35 keV for the telescope (ii) the second one, called CD-PAD detector[5], is composed of a thin ($\sim$40μm) double-sided stripped Silicon detector and a 1.5 mm thick Silicon detector covering from 5 to 25 degrees in the laboratory frame with an energy resolution of 50 keV. Rough calibration of Silicon telescopes was performed with 3α source. Then, more accurate calibration was obtained from ^{17}O runs and comparison with a previous measurement in direct kinematics of the ^{17}O(p,p)^{17}O reaction[6]. Moreover, the contamination from ^{17}Ne decay by βp (90%) was avoided by the use of a target rotating at 1000 rpm. It was supplemented by a MultiChannel Plate (MCP) detector for time of flight (TOF) measurement with an efficiency close to 100%.

3. Analysis and Results

The selection of the kinematic line from TOF measurement and of protons from ΔE-E identification matrix makes it possible to reconstruct the excitation function.

This latter is shown on Fig. 1 (right) where all rings' contributions in the CDPAD detector have been summed after correcting from the angle of emission dependence. The excitation function shows two contributions: the Rutherford scattering (mainly at low energy) and some interfering resonances reflecting the compound nucleus ^{18}Na structure. Indeed, the position of these resonances is linked with the excited states of the compound nucleus whereas their widths give access to spectroscopic factors.

3.1. *Ground State*

The first resonance in our excitation energy spectra (see Fig. 1) is found at a S_p=1,54 MeV corresponding to ΔM=25.30(2) MeV. This value is compatible with predictions based on mass measurement[7,8,9] and slightly above the second peak value from ref [2] (see Table 1). From its mirror nucleus ^{18}N spectroscopic information[10]

Table 1. Mass excess (in MeV) of ^{18}Na from several references.

Theory				Measurement	
Audi [7]	Jänecke [8]	Pape[9]	Fortune[3]	Zerguerras [2]	This paper
25.3 (4)	25.4 (2)	25.7 (2)	24.88	24.19 (16) /25.04(17)	25.30 (2)

(see Fig. 2), the ground state (g.s.) spin should be 1^-. However the shape of a 1^- spin resonance obtained with the R-matrix theory code Anarχ[11] is not compatible with our peak. Only fits with 2^- or maybe 3^- spins lead to good agreement. Thus

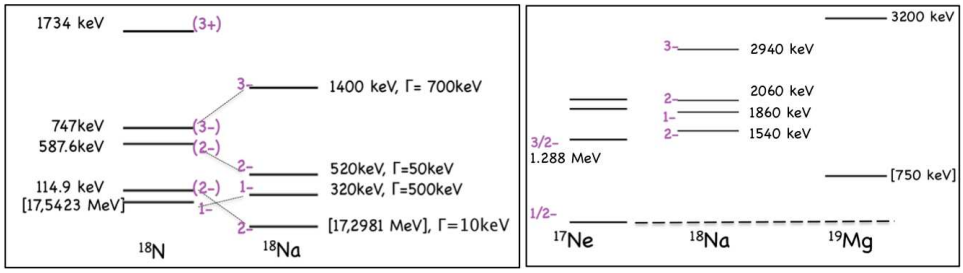


Fig. 2. Left: Level schemes for ^{18}Na as found from the Anarχ fit and for ^{18}N, its mirror nucleus. Right : Level scheme for two-protons radioactivity of ^{19}Mg.

there are two possibilities : (i) either our first resonance is not the ground state and there is a narrow resonance (Γ <5 keV) at lower energy that was not seen in this experiment ; (ii) or there is a spin inversion between ^{18}Na and its mirror nucleus. In the first case, the position of the g. s. of ^{18}Na was inferred from a fit of the 1^- g. s. of ^{18}N with a Woods-Saxon nuclear potential model. It shows that this state

should be located at an energy higher than 1.1 MeV with a width lower than 3 keV. As it is difficult to see it experimentally even with our 15 keV resolution in center-of-mass framework, we have tried to fit the excitation function with a 1^- state at low energy with no success. On the other hand, the second scenario is difficult to understand as the Coulomb shift tends to lower down the 1^- state.

3.2. *Excited States*

The best fit obtained with Anarχ takes into account four resonances and leads to the level scheme of Fig. 2. In the scenario of ref. [2] where the peak at ΔM=25.04 MeV corresponds to the g.s. mass excess, the peak at ΔM=24.19 MeV corresponds to the decay of an excited state of ^{18}Na to the first excited state of ^{17}Ne at E*=1.288 MeV with a width of 230 (100) keV. It would place this excited state of ^{18}Na at E*=0.44 MeV. In order to look for a compatible state in our level scheme, the

Table 2. Wigner width for the decay of excited states of ^{18}Na to the first excited state of ^{17}Ne.

Excited state of ^{18}Na	320 keV	520 keV	1400 keV
Γ_{Wigner} to ^{17}Ne* (1.288 MeV)	21.8 keV	105.6 keV	72 keV

maximum width for each excited state of ^{18}Na decaying to the first excited state of ^{17}Ne has been calculated (see Tab. 2). The 1^- state at 320 keV has a too small Wigner width but the 2^- state at 520 keV seems to be a good candidate.

4. Conclusion

From resonant elastic scattering method, we have found several states in ^{18}Na but spin assignment remains difficult. Moreover, whether the first resonance corresponds to the ground state or not is difficult to assess for the moment. Further theoretical calculations are needed to improve our understanding of the ^{18}Na level scheme.

References

1. B. Blank and M. Płoszajczak, *Rep. Prog. Phys.*, **71** (2008) 046301 and ref. therein.
2. T. Zerguerras *et al*, *Eur. Phys. J. A*, **20** (2004) 389.
3. H. T. Fortune and R. Sherr, *Phys. Rev. C*, **72** (2005) 034304.
4. F. de Oliveira Santos *et al*, Eur. Phys. J. A **24** (2005) 237.
5. A.N. Ostrowski *et al*, *Nucl. Instr. and Meth. A*, **480** (2002) 448.
6. J.C. Sens, S. M. Rafaei, A. Ben Mohamed and A. Pape, Phys. Rev. C **16** (1977) 2129.
7. G. Audi, A.H. Wapstra, Nucl. Phys. A 595 **1995** 409.
8. J. Jänecke, P. Masson, At. Data Nucl. Data Tables **39** (1988) 265.
9. A. Pape and M. Antony, At. Data. Nucl. Data Tables **39** (1988 201.
10. D. R. Tilley, H. R. Weller, C. M. Cheves, and R. M. Chasteler, Nucl. Phys. A **595** (1995) 1.
11. E. Berthoumieux, B. Berthier, C. Moreau, J.P. Gallien and A.C. Raoux, *Nucl. Instr. and Meth. B*, **136-138** (1998) 55.