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ELASTIC AND INELASTIC PROTON SCATTERING ON THE UNSTABLE ^{20}O NUCLEUS MEASURED WITH THE "MUST" DETECTOR ARRAY

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Abstract.
A 43 MeV/nucleon ^{20}O secondary beam obtained by using the SISSI solenoid at GANIL was scattered on a CH_2 target. The angle and energy of recoiling protons were measured with the MUST silicon-strip array yielding angular distributions for elastic and inelastic proton scattering towards the first 2^+ and 3^- states. For comparison, data was also measured for the stable isotope ^{18}O. A phenomenological analysis yields deformation parameter values $\beta_2 = 0.50(4)$ and $\beta_3 = 0.45(5)$ for ^{20}O. A microscopic analysis performed by using the QRPA shows the importance of the pairing effect in these non-closed shell nuclei and allows the validity of different interactions to be tested.

INTRODUCTION

A subject of current interest is the evolution of density and transition density distributions for nuclei far from stability. The measurement of angular distributions of elastic and inelastic proton scattering allows theoretical predictions of these quantities to be tested through microscopic folding model analyses. Such reactions are performed in inverse kinematics, where the radioactive nucleus of interest bombards a target containing protons. An efficient method to gain access to the excitation energy and scattering angle characterizing the reaction is to measure the energy and angle of the recoiling proton. To perform such experiments, a silicon-strip array named MUST [1] was recently constructed in collaboration between IPN-Orsay, CEA Bruyères-le-Châtel and CEA Saclay. In the following we will report on the preliminary results obtained for the ^{18,20}O(p,p') reactions measured at GANIL as a first experiment with the MUST array. Both phenomenological and microscopic Quasiparticle Random-Phase Approximation (QRPA) analyses will be described and conclusions on the importance of the pairing effect as well as on the validity of different interactions for these unstable non-closed shell nuclei will be drawn.

EXPERIMENT

We have measured at GANIL ^{20}O(p,p') angular distributions of elastic and inelastic scattering towards the first collective 2^+ and 3^- states. ^{18}O scattering was also measured for comparison. The secondary beams, produced by fragmentation of a 77 MeV/u ^{40}Ar beam and refocused with the SISSI solenoid, impinged on a 2mg/cm^2 CH$_2$ target. The ^{20}O beam had an intensity of approximately 5.10^3 pps and was 98% pure. The energy of the secondary beam was 43 MeV/nucleon. The ^{18}O beam, also produced by fragmentation, had the same energy per nucleon as ^{20}O and an intensity of 3.10^4 pps.

The angle and energy of recoiling protons were measured by the MUST array [1]. The array is composed of 8 telescopes consisting of a 300 μm silicon-strip detector with 60 vertical and 60 horizontal strips of 1 mm wide, backed by a 3

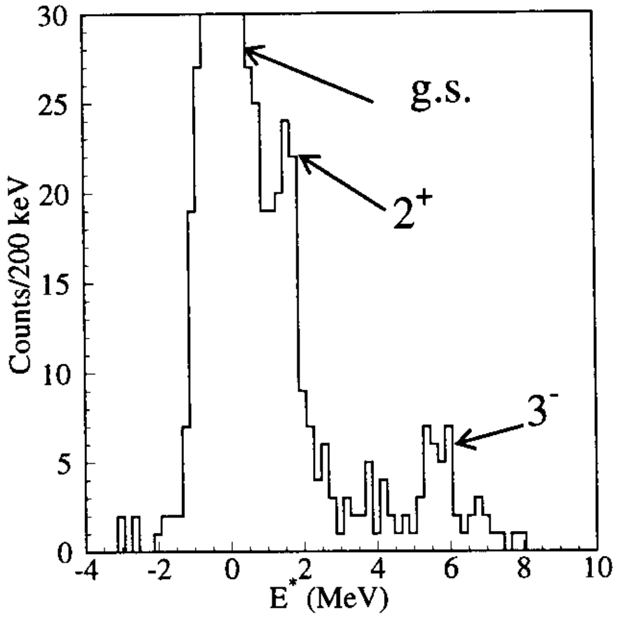

FIGURE 1. Excitation energy spectrum of ^{20}O deduced from the kinematics of the reaction. In addition to the ground state, the first 2^+ and 3^- states are clearly identified.

mm Si(Li) detector and a 15 mm CsI detector, read out by a photodiode. These telescopes can stop protons up to 70 MeV. In this first experiment only 4 telescopes were available. The telescopes were placed at 20 cm from the target and covered laboratory angles from 54° to 82°. Low energy particles which stopped in the strip detector were identified by an energy and a time of flight measurement and higher energy particles by the ΔE-E method. The time resolution of the strip detectors was better than 1ns.

Two low pressure multi-wire proportional chambers [2] were used for beam tracking in order to correct event by event for the incident position and angle of the beam on the target. The position resolution of each detector was approximately 0.8mm. One of the detectors also furnished the start signal for the time of flight measurement. The scattered projectiles were detected in the SPEG spectrometer [3] in coincidence with recoiling light particles.

EXPERIMENTAL RESULTS AND PHENOMENOLOGICAL ANALYSIS

The excitation energy spectra and the angular distributions for reactions studied were extracted from the energy and angle of recoiling protons by using relativistic

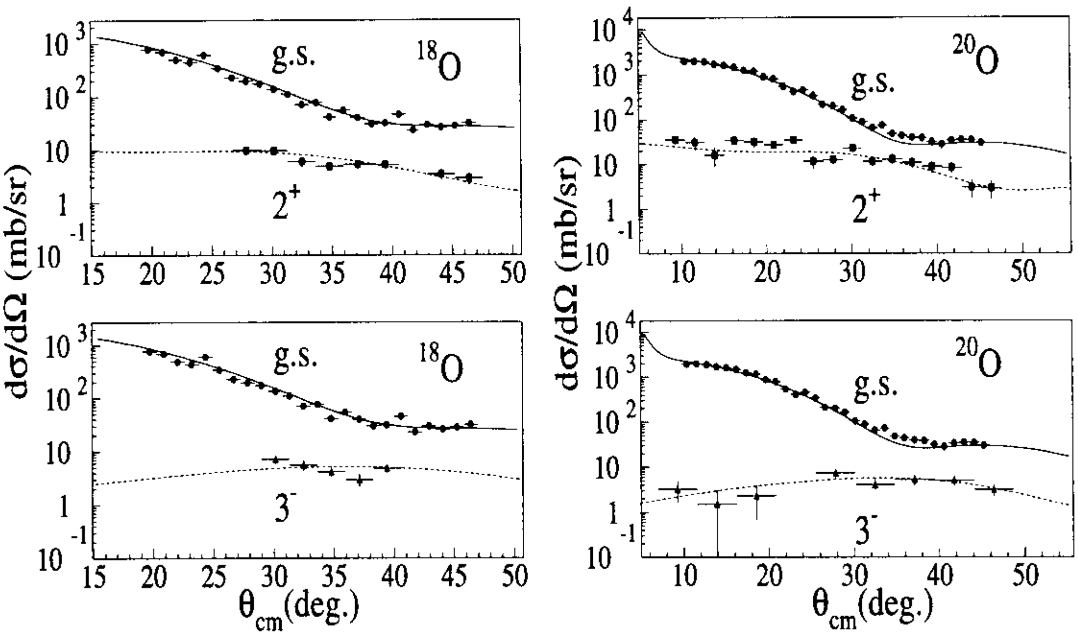

FIGURE 2. Angular distributions for the $^{18}O(p,p')$ and $^{20}O(p,p')$ reactions at 43 MeV/nucleon. Solid and dashed lines correspond to angular distributions calculated by using the code ECIS (see text).

two-body kinematics. Figure 1 shows the excitation energy spectrum of ^{20}O. The first 2^+ and 3^- states show up at energies of 1.7 MeV and 5.7 MeV in agreement with the adopted values of ref. [4]. The excitation energy resolution is around 700 keV and is mostly due to the resolution of the angle measurement of the recoiling protons.

Elastic and inelastic angular distributions towards the first 2^+ and 3^- states for ^{18}O and ^{20}O are shown in fig.2. The normalization is obtained from the number of incident beam particles counted by the tracking detector and the target thickness. The solid and dashed lines correspond to coupled channel predictions using the ECIS code [5] for elastic and inelastic scattering, respectively. The optical potential was obtained from the Becchetti-Greenlees parameterization [6] developed for proton scattering on medium heavy nuclei. This parameterization was recently used for the proton scattering data measured for ^{38,40}S neutron rich nuclei, yielding very satisfactory results [7,8]. In the present case a remarkably good agreement is obtained between the calculated elastic and inelastic angular distributions and the data for both nuclei. In the case of inelastic scattering, the multipolar deformation parameters are obtained by normalizing the calculations to the data. These parameters are $\beta_2 = 0.40(5)$ and $\beta_3 = 0.35(4)$ for ^{18}O and $\beta_2 = 0.50(5)$, $\beta_3 = 0.45(5)$ for ^{20}O.

	E* (MeV)	β_{em} from ref. [9]	$\beta_{(p,p')}$ from ref. [10], [11]	$\beta_{(p,p')}$ this work	$\frac{M_n/M_p}{N/Z}$ this work
^{18}O 2^+	1.98	0.355 (8)	0.37 (3), ref. [10]	0.40 (5)	1.16 (30)
^{18}O 3^-	5.09		0.39 (6), ref. [10]	0.35 (4)	
^{20}O 2^+	1.67	0.261 (9)	0.50 (4), ref. [11]	0.50 (5)	2.12 (27)
^{20}O 3^-	5.61			0.45 (5)	

TABLE 1. Compilation of deformation parameters and deduced $\frac{M_n/M_p}{N/Z}$ values.

The extracted $\beta_{2,3}$ values are compared to values reported from other (p,p') experiments as well as to the electromagnetic values obtained from Coulomb excitation and life time measurements, in table 1. In the case of ^{18}O both β_2 and β_3 values are very similar to those reported previously. For ^{20}O the β_2 value was recently measured at the NSCL/MSU [11] and is confirmed by our measurement while the deformation parameter for the 3^- state is reported here for the first time. A clear increase of the deformation parameter values is observed for both 2^+ and 3^- states when moving from ^{18}O to ^{20}O in agreement with the evolution expected when increasing the neutron excess compared to the N=8 closed shell. Electromagnetic β values, typically obtained either through life time measurements or Coulomb excitation experiments, reflect only the proton contribution while the β

values obtained from (p,p') scattering are mostly sensitive to neutrons. For ^{20}O $\beta_{2(p,p')}$ is almost twice β_{2em}, clearly indicating a large neutron contribution in the excitation of the first 2^+ state.

In the phenomelogical analysis, the ratio of the multipole transition matrix elements M_n/M_p can be determined by comparing the results of different external probes, such as proton scattering and life time measurements in our case. The ratio M_n/M_p is derived in ref. [12]:

$$\frac{M_n}{M_p} = \frac{b_p}{b_n}\Big(\frac{\beta R_{p,p'}}{\beta R_{em}}\Big(1 + \frac{b_n}{b_p}\frac{N}{Z}\Big) - 1\Big)$$

where b_p and b_n are the interaction strengths of protons with protons and neutrons, respectively. In the case of inelastic proton scattering at a few tens of MeV incident energy, the value of b_n/b_p is about 3 [13]. By using electromagnetic transition strengths from ref. [9], $M_n/M_p = (1.16\pm0.30)N/Z$ and $M_n/M_p = (2.12\pm0.27)N/Z$ were obtained for the first 2^+ states in ^{18}O and ^{20}O, respectively. The ^{20}O value is incompatible with the value of N/Z expected for a pure isoscalar mode and thus indicates a large isovector component in the excitation, probably due to a strong interaction between valence neutrons and the core neutrons [11].

MICROSCOPIC ANALYSIS

Phenomenological analyses as described above have been extensively performed for stable nuclei. However, this analysis supposes similar density distributions for neutrons and protons, an assumption which can be particularly misleading in the case of neutron-rich nuclei where effects such as neutron skins are expected. Therefore, we have undertaken a microscopic analysis of the data by developing a self-consistent QRPA model. This model takes into account the pairing effect which is expected to be important for open shell nuclei. QRPA excitations are built on self-consistent Hartree-Fock(HF)+BCS calculations using Skyrme type effective interactions and a constant gap pairing interaction. The HF+BCS method is described in ref. [14]. It is noted that this QRPA calculation is self-consistent and only depends on the Skyrme and the pairing interactions adopted at the very beginning of the computation.

The proton contribution to the reduced electric quadrupole transition probability $B(E2)_p$ is obtained from the calculations by integrating the proton transition density:

$$B(E2)_p = \Big[\int \delta\rho_p(r) r^4 dr\Big]^2$$

Figure 3 (left side) shows these values for different oxygen isotopes calculated either in the framework of a simple RPA or in the framework of the QRPA by using different Skyrme interactions : SIII, SGII, SLy4. For the QRPA a constant gap pairing interaction has been used, according to the formula : $\Delta = 12 MeV.A^{-1/2}$ from ref. [15]. Experimental values for ^{18}O and ^{20}O deduced from life time measurements and reported in ref. [9], are also displayed. It is noted that the QRPA has generally a good agreement while the RPA fails to reproduce the data. This indicates that it is important to properly treat the pairing in non-closed shell nuclei. Strong variations depending on the different interactions are observed. It appears that the best agreement for oxygen isotopes is obtained with SGII.

Similar conclusions can be drawn for the M_n/M_p ratios (fig.3, right side). Again the best agreement with the weighted mean of experimental M_n/M_p values taken from this work and ref. [11], is obtained with QRPA. It would be now very interesting to have experimental data for ^{22}O in order to confirm the decrease of the $B(E2)_p$ and the slight increase of the M_n/M_p value predicted by the calculations. The quantities studied here, $B(E2)_p$ and M_n/M_p, are obtained by integrating the density distributions over the radius an cannot give direct informations on the density profiles. In order to probe the possible neutron skin in these nuclei, folding model calculations are necessary and currently in progress. In these calculations the density distributions are folded with the nucleon-nucleon interaction providing

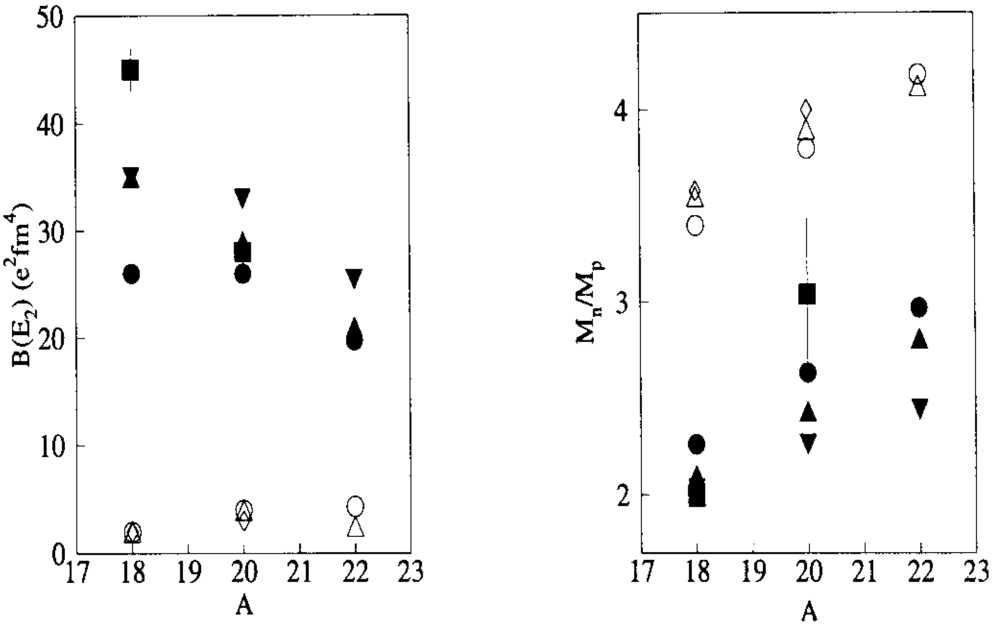

FIGURE 3. RPA (open symbols) and QRPA (filled symbols) calculations for proton contribution to reduced electric quadrupole transition probability $B(E2)_p$ (left) and M_n/M_p ratio (right) in the case of neutron-rich oxygen isotopes. Three Skyrme effective interactions have been used both for RPA and QRPA : SIII (circles), SGII (up triangles) and SLy4 (open diamonds for RPA and filled down triangles for QRPA). Experimental values are presented by the black squares.

potentials which are injected in DWBA calculations in order to get cross sections which can then be compared to experimental angular distributions.

CONCLUSIONS

The use of silicon-strip arrays to measure recoiling light particles is a powerful method to obtain light hadron scattering data for unstable nuclei. Proton scattering on ^{20}O and ^{18}O was recently studied at GANIL using the MUST array. The measured angular distributions for elastic and inelastic scattering towards the first 2^+ and 3^- states are in good agreement with coupled channels calculations using phenomenological optical potentials. A strong increase of the deformation parameter values as well as M_n/M_p ratios is observed when moving from ^{18}O to ^{20}O indicating the importance of the neutron contribution to the excitation. The comparison of the data to microscopic calculations shows that the pairing effect is important for these nuclei, as attested by the good agreement obtained with the QRPA calculations. In the near future, folding model calculations with the QRPA densities will provide insight into the neutron skin which may exist in these nuclei.

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