Study of low-lying resonance states in ^{16}F using an ^{15}O radioactive ion beam

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Among the A=16, T=1 isobaric triad, many states in ^{16}O and ^{16}N have been well established, but less has been reported about ^{16}F. Four states of ^{16}F below 1 MeV have been identified experimentally, and their energies are currently known to an accuracy of 4-6 keV [1] (the next known state of ^{16}F lies at 3.76 MeV). Experimental studies with stable beams have established spin-parity values for theses low-lying states, but only upper limits or rough estimates of their level widths have been reported. The main difficulty in studying ^{16}F is that it can be reached by relatively few reactions, such as ^{14}N(^{3}He,n) [2], ^{19}F(^{3}He, ^{6}He) [3], ^{16}O(^{3}He,t) [3,4], and ^{16}O(p,n) [5].

All the states in ^{16}F are unbound to ^{15}O+p. The spins and parities of the low-lying states have been found to be 0^-, 1^-, 2^-, and 3^- in ascending order in energy, and are believed to have ^{15}O core-single proton configurations such as $1p_{1/2}^{-1}$ $2s_{1/2}$ for the 0^-, 1^-, and $1p_{1/2}^{-1}$ $1d_{5/2}$ for the 2^-, 3^-. However, the variation in the $1d_{5/2}$-$2s_{1/2}$ energy level difference across the members of the A=16, T=1 isobaric triad made initial ^{16}F spin assignments uncertain, since ^{16}N showed $J^\pi = 2^-, 0^-, 3^-, 1^-$ for the four levels in ascending order while $J^\pi = 0^-, 2^-, 1^-, 3^-$ arose in ^{16}O.

A recently developed ^{15}O ($T_{1/2}$ = 122 sec.) radioactive ion beam from the BEARS (Berkeley Experiments with Accelerated Radioactive Species) facility was used to study the structure of ^{16}F using ^{15}O+p elastic scattering and the Thick Target Inverse Kinematics (TTIK) method on a polyethylene target. The process developed for the ^{14}O beam [6] was used for ^{15}O production, but the gas target was loaded with $^{15}N_2$ instead of $^{14}N_2$. In addition, the unloaded $^{15}N_2$ gas was stored and re-injected into the target cell using a recycling mechanism [7]. In this experiment, the average beam intensity of ^{15}O on target was about 4.5×10^4 pps, and the beam energy spread was about 1.7 MeV FWHM.

The setup was similar to that given in Ref. [8], but was in Cave-0 rather than Cave-4A. The 120 MeV ^{15}O beam was slowed down by a 3.81 μm Ni degrader, and completely stopped in a thick 200 μm (18.4 mg/cm^2) CH_2 target. The main particle telescope was composed of 30 μm, 700 μm, and 5,000 μm thick silicon detectors, located at a distance of 10.9 cm from the target at 0°. The first two detectors were thick enough to detect protons from the four low-lying resonance states in ^{16}F, and the third one permitted the detection of higher energy protons up to 7 MeV in the center-of-mass (c.m.). The total energy resolution was estimated to be 28 keV FWHM in the c.m., including contributions from electronic noise, detector/setup geometry, and beam straggling in the CH_2 target.

Figure 1 presents the results from 0.4 to 3 MeV in the c.m. The energy calibration for the system was done by using ^{15}N(p,p) reactions before and after the main ^{15}O(p,p) measurement, since the energy levels of the relevant excited states in ^{16}O are well known. The uncertainty in the energy calibration was estimated to be about ±15 keV in the c.m. frame. In this study, the earlier ^{12}C(^{14}O,p) reaction data [8] were adopted to estimate the proton background - a very broad distribution for the background proton spectrum. This proton background appears to be small in the region of the sharp proton peaks from the four low-lying resonances.

Our data analysis focused on determining the level widths of the first four states in ^{16}F so that only the low energy region below 3 MeV in the c.m. was used for an R-matrix analysis. The results of this analysis are shown in Fig. 1 as well as the fitted background function. Some of the preliminary level widths that have been obtained differ from compiled values from the previous studies. The level widths of the 0^-, and 1^- states were reported to be 40 ± 20 keV, and less than 40 keV, respectively in Ref. [1]. Our results suggest that the 0^- state has a level width of 23.3 ± 1.6 keV, and that the broader 1^- state has a width of 87.6 ± 2.4 keV (about twice the compiled value). Interestingly, similar results of ~ 25 keV and ~ 100 keV were reported for the 0^- and 1^- state, respectively, in Ref. [4], which is consistent with this work. The level width of the 2^- state is found to be 3.4 ± 0.6 keV which is much narrower than the compiled value of 40 ± 30 keV, while 13.9 ± 1.5 keV for the 3^- state is in good agreement with < 15 keV given in Ref. [1].

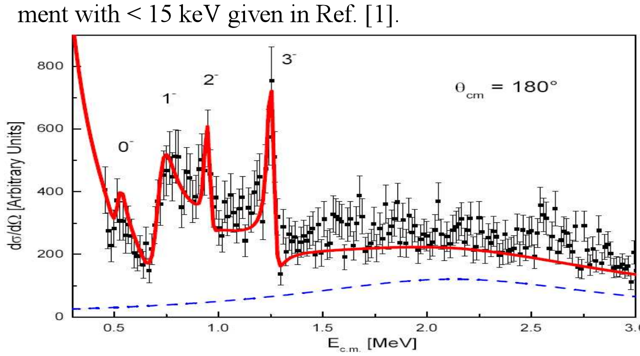

FIG. 1: (Color online) The center-of-mass excitation function for ^{15}O+p elastic scattering. The solid line presents the R-matrix fit, with the background function shown by the dashed line.

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