First observation of ^{14}F

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In an experiment conducted at the Cyclotron Institute at Texas A&M University in March-April 2009, the resonant elastic scattering of ^{13}O+p was studied with the Thick Target Inverse Kinematics (TTIK) method [1] to observe states in ^{14}F. ^{14}F is expected to be unbound to proton decay (as are ^{15,16}F). A rare beam of ^{13}O with intensity of 5 x 10^3 pps was produced for the experiment in the ^{1}H(^{14}N,^{13}O)2n reaction and was separated using MARS. Further details about the production of the ^{13}O beam and the experimental setup can be found in [2,3] as well as in the TAMU annual report for 2009.

Fig. 1 presents the excitation functions for the ^{13}O+p elastic scattering obtained in the measurement as compared with R-Matrix calculations. The top panel displays the data for ^{13}O+p where a

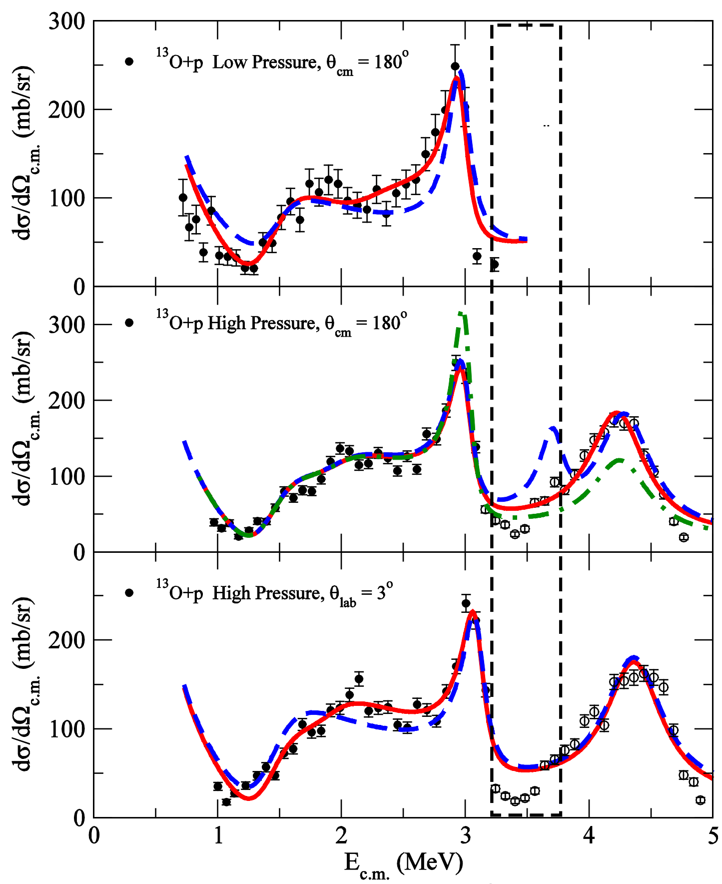

FIG. 1. Excitation functions for the ^{13}O+p elastic scattering compared with R-Matrix calculations. See text for further explanation.

lower CH_4 pressure (930 mbar) was used for the gas in the scattering chamber at θ_{cm} = 180° (θ_{lab} = 0°). These measurements allowed for better observation of the low energy part of the excitation function that was found to be related to the position of the ^{14}F ground state. The best fit to the data in the region between 0.7 MeV < E_{cm} < 2.5 MeV was observed when the ground state of ^{14}F was assumed to have J^{π} = 2^-. The assumption of a 2^- ground state agrees with the ab-initio [4] and shell model predictions [5], as well as the data from the mirror nucleus ^{14}B [6] (see figure 2). By contrast, a 1^- ground state would be too weak to provide for the deep minimum in the excitation function at E_{cm} ≈1.2 MeV as shown by the dashed line in Fig. 1.

Data from the ^{13}O+p measurements at higher CH_4 pressure (1040 mbar) are presented at θ_{cm} = 180° (θ_{lab} = 0°) in the middle panel of figure 1 and at θ_{lab} = 3° in the bottom panel of Fig. 1. At higher gas pressures, it was possible to obtain data for the ^{13}O+p excitation function up to E_{cm}≈ 5 MeV. The best overall fit to the data was obtained with the level scheme and resonance widths listed in Table I (as shown by the solid line in each plot). However, other values for the spins of these states were considered. First, as shown in the bottom panel, a 1^- excited state at 2.1±1.7 MeV was added. This level, while not immediately obvious in an inspection by eye, is suggested by the *ab-initio* [4] and shell model calculations [5], and data from ^{14}B. The inclusion of this level improves the fit to the data by≈40% in χ^2 versus the exclusion of this level in the calculation. Including a state with higher spin (l >0) would produce a peak in this region that is too narrow to fit the data. Next, the peaks at E_{cm} = 3 MeV and 4.3 MeV were considered (middle panel, figure 1). These peaks were fit by *d*-wave resonances (l=2) with large reduced widths and with spins 3^- and 4^- respectively. As shown by the dot-dashed line, exchanging the 3^- and 4^- spins in the R-matrix calculation results in a cross section that is too high for 3 MeV resonance and a cross section that is too low for the 4.3 MeV peak.

TABLE 1. Levels in ^{14}F.

E* (MeV)	J^{π}	Γ (keV)	Γ/Γ_{sp}
1.56±0.04	2^-	910±100	0.85
2.1±0.17	1^-	~ 1000	0.6
3.05±0.60	3^-	210±40	0.55
4.35±0.10	4^-	550±100	0.5

It should be noted that the region of the excitation function shown between 3.12 MeV < E_{cm} < 3.6 MeV (as illustrated by the dashed box in Fig. 1) is distorted due to a thin dead layer in the back of the front Si detectors and to signals in the back (veto) Si detectors that were below the electronics threshold. As a result of this distortion, a resonance in this region would not be observed in our measurements. The shell model calculations and comparison with ^{14}B both predict a second 2^- state in ^{14}F between the 3^- and the 4^-. A calculation with this state included is shown in the dashed-line of the middle panel of Fig. 1. While the current data suggests that this resonance is not there, the calculation shows that its presence does not distort the other states in the excitation function. A future measurement with thicker Si detectors could better determine the parameters for this region of the excitation function.

The level scheme for ^{14}F as compared with the *ab-initio* [4] and shell model calculations [5], as well as the ^{14}B level scheme [6] is shown in Fig. 2. The experiment showed that ^{14}F was unstable to proton decay by 1.56 MeV. The measured level scheme and the separation of the states are in reasonable agreement with the *ab-initio* calculations and ^{14}B. However, the *ab-initio* calculations [4] and other previous predictions for ^{14}F [7,8] expected it to be unstable to proton decay by ~3 MeV. While new calculations are needed to specify the necessary corrections to the theoretical calculations, part of the disagreement between the predictions and the present work should be related with the Thomas-Ehrman

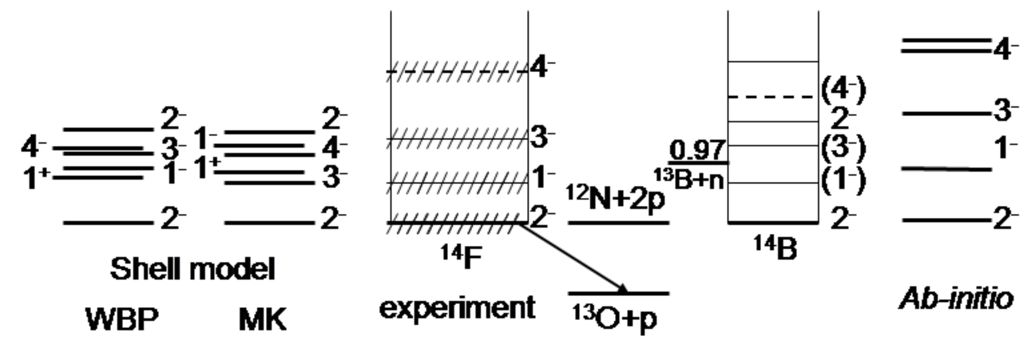

FIG. 2. Level scheme for ^{14}F compared with ab-initio calculations [1], shell model calculations [5], and the ^{14}B level scheme.

shift [9,10] and the single-particle structure of the states measured in ^{14}F (as determined in the R-Matrix calculations). A detailed discussion of this difference can be found in the upcoming paper [2]. It also should be noted that the shell model calculations produce a much more compressed level scheme than the measured data and the *ab-initio* calculations. This could indicate that the residual interactions should be modified to provide for a better description of nuclei beyond the proton dripline.

In summary, data for the previously unknown ^{14}F nucleus were measured with the ^{13}O+p reaction using the TTIK. The ground state and low-lying excited states were observed, and their spins and parities were determined by comparison with R-Matrix calculations. It is worthwhile to note that these measurements were made with a ^{13}O beam of relatively weak intensity (5 x 10^3 p/s) and initial energy of 31 MeV/u degraded to 11 MeV/u. Such an experimental approach should be useful in future measurements where a very rare beam with a short lifetime is needed at low energy.

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