Gamma-Ray Transitions in ^{20}F†

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The γ-ray decay of the levels of ^{20}F at 1824, 1843, and 3176 keV has been studied. Results indicate that each of these levels has only one mode of decay. For the 1824-keV level this finding is consistent with the $L=4$ transfer reported by Fortune and Crozier. Together with previous angular-correlation results this determines the probable assignments $J^{\pi}=5^{+}$ for the 1824-keV level and $J=4$ for the 823-keV level. This and other recent experimental developments are in good agreement with published calculated ^{20}F structure by Halbert, McGrory, Wildenthal, and Pandya.

I. INTRODUCTION

The levels at 1824- and 1843-keV excitation in ^{20}F are known to decay by γ-ray emission, primarily to the 823-keV level and primarily to the ground state, respectively.[1,2] In previous work on the $^{18}O(\tau, p)^{20}F$ reaction, with NaI(Tl) γ-ray detectors in coincidence with surface-barrier proton detectors, the energy resolution has not been adequate for the branching ratios of the states to be determined separately. Somewhat fortuitously, certain combinations of beam energy and proton angle were found for which the yield of one state or the other was a relative minimum, and measurements of the γ-ray spectra at these points allowed upper limits to be determined, of 5% for the 1843→823-keV branch and 20% for the 1824-keV→ground-state branch.

Interest has been rekindled[3-6] especially in the second of these figures. Specifically, the speculation that the 823- and 1824-keV levels have $J^{\pi}=4^{+}$ and 5^{+}, respectively, would accord with calculations based either on shell-model states[7] or on mixed rotational bands.[3] However, this would imply that the reported 1824-keV→ground-state transition would be of $M3$ multipolarity, competing successfully with the $M1E2$ 1824→823-keV branch, which would of course be completely unacceptable. Therefore, we have investigated more closely the decay of these states.

II. PROCEDURE

We have measured with Ge(Li) detectors the γ-ray spectra in coincidence with protons feeding selected levels of ^{20}F, using the reaction $^{18}O(\tau, p)$-^{20}F. In one experiment a 16-cm^3 detector was used at 90° with respect to the beam direction, and in another this was replaced by a 50-cm^3 detector at 55°. In other respects the two experiments were essentially alike and will be treated as one.

A target of $Al_2{}^{18}O_3$ was bombarded with 3.90-MeV $^3He^+$ ions from the Notre Dame 4-MV electrostatic generator. Protons were detected near 180° in an annular surface-barrier detector covered with a 7-mg/cm^2 Al absorber to exclude elastically scattered τ particles. Coincident γ-ray signals, encoded into 1024 channels, were routed into three memory areas according to the proton energy of each event, corresponding to (a) excitation energy of 1600 to 1950 keV in ^{20}F, encompassing the 1824-1843-keV doublet, (b) excitation of 3000 to 3300 keV in ^{20}F, and (c) all other proton energies down to an excitation of approximately 5000 keV. A fourth memory area was used to store chance events gated by a delayed coincidence circuit.

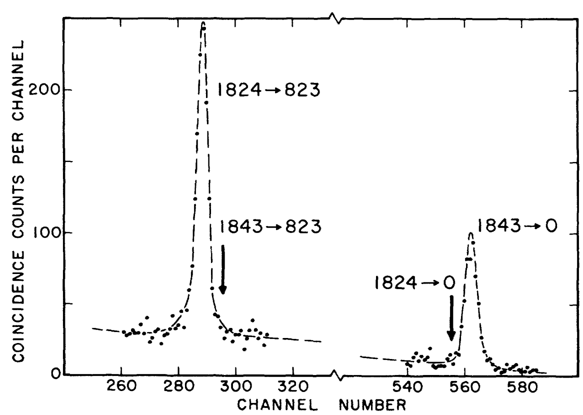

FIG. 1. Two portions of the γ-ray spectrum in coincidence with protons feeding the 1824-1843-keV doublet. Arrows indicate the positions at which one would expect peaks corresponding to the transitions 1843→823 and 1824→0 keV.

III. RESULTS

In spectrum (c), not specialized to selected individual levels, about 12 coincidence peaks were readily identified with known transitions among ^{20}F levels. The γ-ray energy resolution attained in the present experiments was only 10 keV full width at half maximum, which, combined with appreciable drifts which occurred between calibrations, precluded good γ-ray energy measurements. All of the observed energies are consistent within ±5 keV, and usually much less, with the level energies of Rollefson, Jones, and Shea.[8] The intensities of the γ rays observed at 55° are also consistent with previously reported branching ratios.

Figure 1 shows part of the γ-ray spectrum in coincidence with protons feeding the 1824- and 1843-keV levels, as measured with the 50-cm^3 detector. This corresponds to 16 mC of τ^+ through a target 300 nm thick. Data from the other experiment are similar, with relatively larger statistical fluctuations. No peak is evident, neither at the position corresponding to a 1824→0-keV transition, nor at that of a 1843→823-keV one. Taking into account the variation in efficiency with γ-ray energy, we have determined an upper limit of 3% to the branching of the 1824-keV level to the ground state, and also an upper limit of 3% branching of the 1843-keV level to the 823-keV level. No other branch of either level was observed, as was to be expected from the inherently more sensitive NaI(Tl) measurements.[1,2] The spectra are thus entirely consistent with a unique mode of decay for each level of the doublet. The measurements do not rule out a weak 1824→656-keV line, but none was observed. This part of the spectrum is contaminated with the 1970→823-keV line, since the particle-energy window contained part of the 1970-keV peak. An upper limit, again 3%, can be placed on the 1824→656-keV branch. Recently, Pronko[6] has reported nearly identical results for the branching of the 1824-keV level.

In the gated spectrum corresponding to 3000–3300 keV in excitation, only those γ rays were observed which correspond to the 3176→984→0-keV cascade, except for easily recognized interference from $^{27}Al(\tau, p\gamma)^{29}Si$. No indication of alternative decays or of other levels in this range was observed. Since there is a slight discrepancy among published excitation energies of the 3176-keV lev-

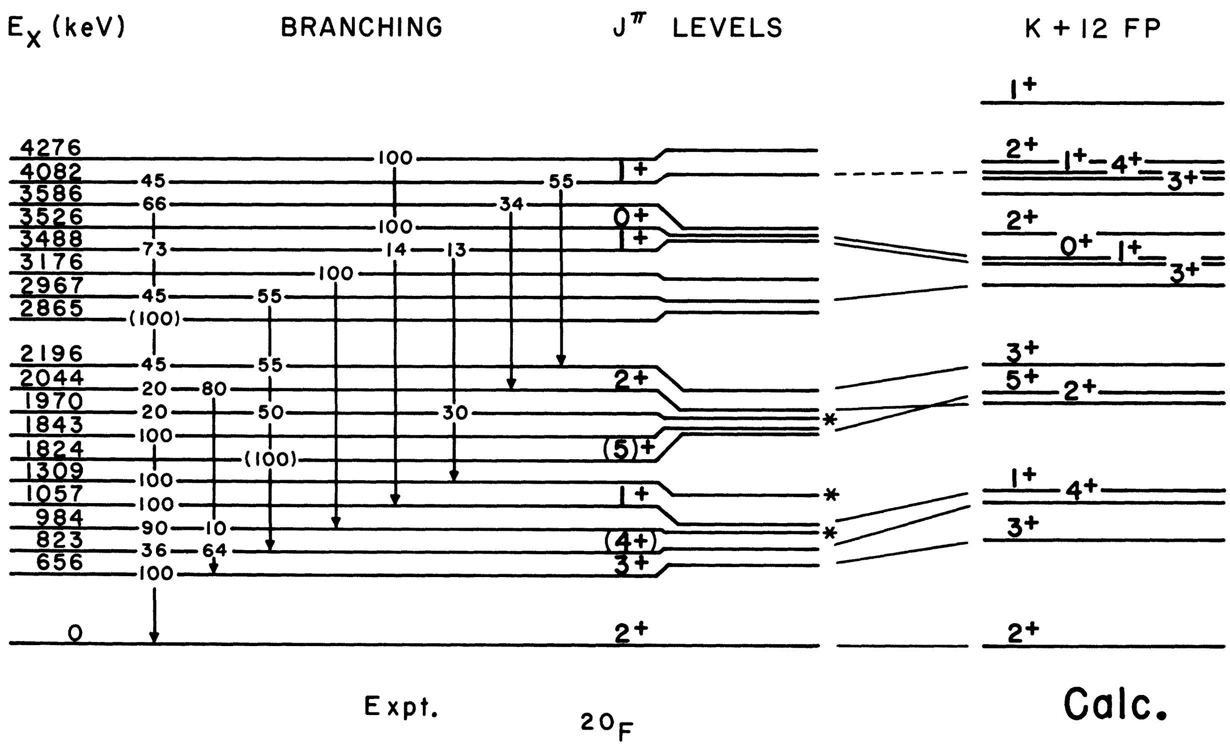

FIG. 2. Current experimental information on ^{20}F compared with levels calculated with the K+12FP potential (see text). Most of the spin-parity assignments are discussed by Fortune *et al.* (Refs. 3 and 5). Excitation energies are mainly those of Rollefson, Jones, and Shea, but above 3586 keV many levels are omitted. Branching ratios through 3176 keV are from Ref. 2 or the present work, and above this value from Refs. 9–11. Levels marked with an asterisk (*) have probably other than 2*s*1*d*-shell configurations (Ref. 5). Many of the identifications between experimental and calculated states were proposed by Halbert *et al.* (Ref. 7).

el, we have determined the energy of the first transition of this cascade to be 2192 ± 5 keV based on an internal calibration using all the other identified ^{20}F peaks only. This value is in excellent agreement with the excitation energy 3176 keV given by Holtebekk, Tryti, and Vamraak,[9] and within the stated uncertainty of Rollefson's value.[8]

IV. DISCUSSION

The present revision of the 1824-keV level decay scheme removes an impediment to the speculative assignment $J = 5$ to this level. Such a spin value is consistent with angular-correlation measurements[1,2,6] if and only if the 823-keV level has spin 4. It has been repeatedly shown that the 823-keV level can have only $J = 2$ or $J = 4$. Electromagnetic transition rates inveigh against $J = 2$, as discussed in Ref. 2 along with other related evidence. Fortune and Crozier[5] have found that the 1824-keV level is populated by $L = 4$ transfer, without any $L = 2$ component, in ^{18}O(τ, p) at high beam energy, limiting its spin-parity assignment to 4^+ or 5^+. But the angular-correlation measurements[2] do not admit the possibility $J = 4$ for this level. We conclude that probably the 1824-keV level of ^{20}F has $J^\pi = 5^+$ and that the 823-keV level has $J = 4$. (One cannot rigorously exclude the possibility that pure $L = 4$ deuteron transfer populates a $J = 3$ level.)

The new γ-ray decay scheme for the 1824- and 1843-keV levels and the two spin-parity assignments just discussed are shown in Fig. 2 along with much of the existing experimental information about the excited levels of ^{20}F, including some levels[9-11] above the range of the present work. For comparison, a level scheme calculated by Halbert, McGrory, Wildenthal, and Pandya[7] is shown. The calculation was part of that group's work on the representation of all available $A = 18$ to $A = 22$ data with a shell-model basis. The potential denoted K + 12FP was one of the seven used; it was not the one which gave the best over-all agreement for the $A = 18$ to $A = 22$ range and so was given secondary emphasis in their report; nevertheless, Halbert *et al.*[7] did point out its success in fitting such meager ^{20}F data as were then known. The notation K + 12FP is an abbreviation for a realistic interaction, due to Kuo, used in a least-squares optimization with 12 free parameters. The agreement in excitation energies evident in Fig. 2 is matched by a similar accord in spectroscopic strengths.[7,3] Branching and mixing ratios are not expected[3,7] to constitute sensitive tests of models at the present level of sophistication. While there is still ample opportunity for improved calculations, for other models, and for more critical experiments, Fig. 2 illustrates the significant progress in understanding the structure of ^{20}F made in the last few years.

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