PHYSICAL REVIEW C VOLUME 1, NUMBER 1 JANUARY 1970

Beta Decay of F^{21}†

W. R. Harris and D. E. Alburger
Brookhaven National Laboratory, Upton, New York 11973

(Received 17 July 1969)

The β decay of F^{21} has been investigated, utilitzing the $F^{19}(t, p)F^{21}$ reaction to form the F^{21} activity and a 1.3-MeV mechanically-chopped beam. The existence of previously reported β branches to the ground and first two excited states of Ne^{21} has been confirmed, and an upper limit for decay to the third excited state of Ne^{21} has been established by detecting β-γ coincidences and β-ray singles with NaI(Tl) and plastic scintillation detectors. The Ne^{21} levels in keV, F^{21} β branches populating these levels in percent, and corresponding log*ft* values are 0.0, 29±6, 5.23±0.10; 350, 63±6, 4.76±0.05; 1746, 7.6±1.0, 5.07±0.07. The log*ft* values measured in the present work differ markedly from those previously reported. Measurements of the excitation energies of the first two excited states of Ne^{21} yielded (in keV) 350.5±0.3 and 1745.6±0.4, respectively. The upper limit on the percent branch to the third excited state is 0.15%, corresponding to a limit on the log*ft* of 6.0.

INTRODUCTION

PREVIOUS studies of the β decay of F^{21} have established the half-life for the decay and the existence of β branches to the ground and first two excited states of Ne^{21}. A recent determination[1] of the half-life gives 4.35±0.04 sec and is consistent with measurements made previous to that. Kienle and Wien[2] established that F^{21} β decays to the first and second excited states of Ne^{21} with limits on the log*ft* values of ≥ 5.0 and ≥ 5.2, respectively. Bunker *et al.*[3] observed the F^{21} β branch to the Ne^{21} ground state as well as to the first two excited states. Their data indicated log*ft* values of 4.8, 5.2, and 5.2 for β decays to the ground and first and second excited states of Ne^{21}, respectively. The present work was undertaken to obtain more accurate log*ft* values for decays to the ground state and first two excited states of Ne^{21}, and to search for a β branch the 2790-keV level in Ne^{21}. Pronko *et al.*[4] have assigned $J=\frac{3}{2}$ to this level; and if an allowed β decay were observed to the 2790-keV level, its parity would be established as positive since the ground state of F^{21} has $J^{\pi}=\frac{5}{2}^{+}$. The strong coupling model has been applied both to Ne^{21}[5,6] and the low-lying levels of F^{21}[7] with some success. Accurate log*ft* values can in general provide a check on such descriptions of, in this case, the ground state of F^{21} and the first three states of Ne^{21}.

EXPERIMENTAL METHODS AND RESULTS

The F^{21} activity was produced via the $F^{19}(t, p)F^{21}$ reaction utilizing a 1.3-MeV 0.005-μA triton beam from the Brookhaven National Laboratory 3.5-MV van de Graaff accelerator. Targets consisted of CaF_2, KF, or SrF_2 1-2 mg/cm² thick deposited onto steel backings. A fast mechanical chopper[8] located ~12 ft from the target enabled us to study events occurring while the beam was not hitting the target. Since the chopper was operated in a 17-msec cycle composed of 3 msec of irradiation, 2 msec of delay, 10 msec of counting, and 2 msec of delay, data were being collected about 60% of the time.

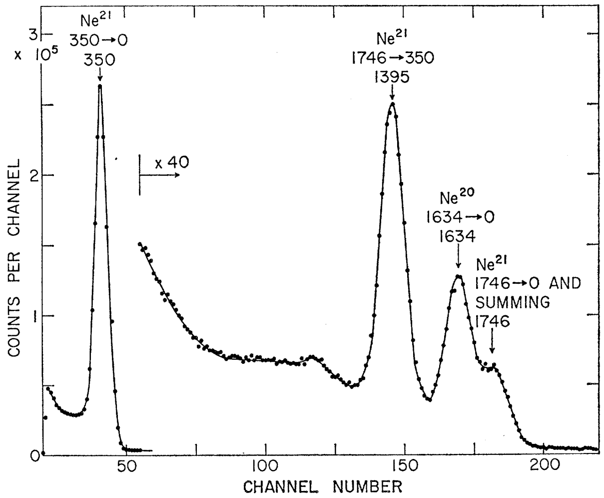

FIG. 1. Delayed γ-ray spectrum in a 5×5-in NaI(Tl) detector in coincidence with β rays detected in a 3-in.-diam by 2-in.-thick Pilot-B scintillator following F^{21} β decay. Shoulder on the Ne^{20} 1634-keV line is due to the ground-state decay of the 1746-keV level in Ne^{21} and summing of the 1395- and 350-keV γ rays in the NaI(Tl) detector.

The target chamber was a thin-walled glass cylinder which allowed both the γ- and β-ray detectors to be placed 2 cm from the target. The β rays were detected with a 3-in.-diam by 2-in.-thick Pilot-B scintillator coupled to an RCA 8575 photomultiplier tube. The γ rays were detected with a 5×5-in. NaI(Tl) detector. A 0.25-in.-thick Al absorber was placed in front of the NaI(Tl) detector in order to cut down the β-ray flux without producing too much bremsstrahlung. The two

---

† Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] J. L. C. Ford, Jr., J. K. Bair, C. M. Jones, and H. B. Willard, Nucl. Phys. **63**, 588 (1965).

[2] P. Kienle and K. Wien, Nucl. Phys. **41**, 608 (1963).

[3] M. E. Bunker, M. G. Silbert, J. W. Starner, R. K. Sheline, and N. Jarmie, Bull. Am. Phys. Soc. **8**, 317 (1963).

[4] J. G. Pronko, C. Rolfs, and H. J. Maier, Nucl. Phys. **A94**, 561 (1967).

[5] I. Kelson and C. A. Levinson, Phys. Rev. **134**, B269 (1964).

[6] A. J. Howard, J. P. Allen, and D. A. Bromley, Phys. Rev. **139**, B1135 (1965).

[7] K. H. Bhatt, Nucl. Phys. **39**, 375 (1962).

[8] D. E. Alburger, Phys. Rev. **131**, 1624 (1963).

detectors were placed collinear and at 90° with respect to the incident beam.

Delayed γ-ray spectra, gated by a β-γ coincidence requirement, and β-ray singles were recorded simultaneously. A typical γ-ray spectrum in coincidence with delayed β's is shown in Fig. 1. The 350- and 1395-keV γ rays follow β feeding of the 350- and 1746-keV states in Ne^{21}, respectively. The 1634-keV γ ray arises from the β decay of F^{20} to the first excited state of Ne^{20}. The F^{20} is formed via the $F^{19}(t, d)F^{20}$ reaction. The peak at about 1746-keV, appearing as a shoulder on the 1634-keV peak, arises from the weak ground-state γ-ray branch of the 1746-keV Ne^{21} level and from summing of the 1395- and 350-keV γ rays from Ne^{21}. The percent β branches to the ground, first excited, and second excited states of Ne^{21} can be computed from the net yields of the 350-, 1395-, 1746-, and 1634-keV γ rays in coincidence with β rays, the recorded β-ray singles, and the fractions of the various β-ray components detected above the β-ray detector bias. The fraction of total β rays above the bias level was determined by linear extrapolation of the plateau in the β-ray spectrum to zero pulse height.[9] Since the fraction of β rays whose pulse-height lies above the bias level depends on the β-ray end point energies, it was necessary to determine this fraction separately for the β-ray singles, β rays feeding the 350-keV level, and those feeding the 1746-keV level. Therefore, spectra of β-ray singles and β rays in coincidence with the 350- and 1395-keV γ rays were recorded. Since the end-point energies of β rays feeding the 350-keV level in Ne^{21} and the 1634-keV level in Ne^{20} are 5.334 and 5.418 MeV, respectively, the fraction of Ne^{20} β rays above the bias was taken to be the same as for those feeding the 350-keV level in Ne^{21}.

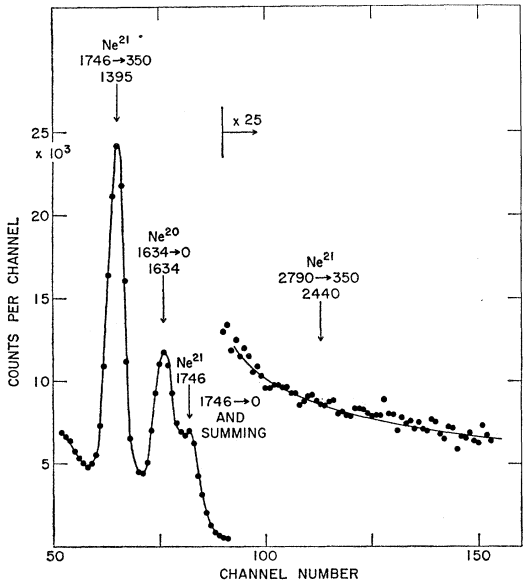

FIG. 2. Delayed γ-ray spectrum in a 5×5-in. NaI(Tl) detector in coincidence with β rays detected in a 3-in.-diam by 2-in.-thick Pilot-B scintillator following F^{21} β decay. This spectrum was used to establish the upper limit on the β branch to the third excited state of Ne^{21}.

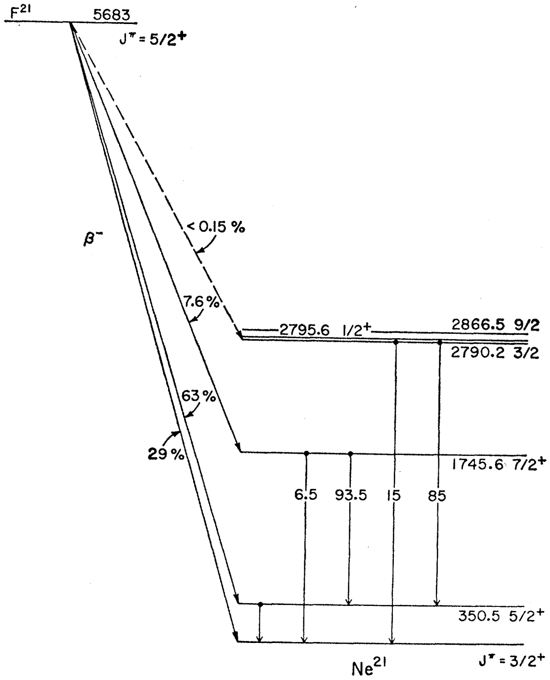

FIG. 3. Proposed decay scheme of F^{21}. The β branches of F^{21} to states in Ne^{21} and the excitation energies of the first two excited states of Ne^{21} are from the present work. The γ-ray branching ratios are from Ref. 11 and the excitation energies of the third, fourth, and fifth excited states are from Ref. 12.

Since F^{20} β decays 100% of the time to the first excited state of Ne^{20}, subtraction from the β-ray singles of those β rays arising from the decay of F^{20} is readily accomplished. Figure 1 reveals no other contaminant γ radiation in coincidence with β rays. A source of error in the β-ray singles measurements arises, however, from the possibility of detecting β rays arising from the decay of nuclei formed by triton bombardment of contaminants that leave the daughter nucleus in its ground state. Hence, there would be no accompanying γ rays. Several steps were taken to check that the only contaminant of the β singles was the F^{20} β rays. First, β-ray singles from a 1.5-mg/cm^2-thick CaF_2 target on a steel backing were detected as a function of time for about 10 sec immediately after the beam was removed from the target. The resulting decay curve had a slope of 4.4 ± 0.1 sec which is in excellent agreement with the known[1] F^{21} half-life of 4.35 ± 0.04 sec. Since this measurement was started about 1 sec after the beam was removed from the target, and since the data to determine the β branches were accumulated with the fast chopper as described above, any β-ray singles to be detected erroneously as arising from F^{21} would have to (1) leave

---

[9] D. H. Wilkinson and D. E. Alburger, Phys. Rev. **113**, 563 (1959).

TABLE I. β-ray branches in the decay of F^{21} for various targets.

Level in Ne^{21} (keV)	Branch (%) CaF_2 target	Branch (%) KF target	Branch (%) SrF_2 target
0	25±6	32±6	30±6
350.5	68±6	60±5	62±5
1745.6	7.4±1.0	7.6±1.0	7.7±0.9

the daughter nucleus in its ground state and (2) have a half-life very nearly equal to that for F^{21}, or considerably less than 1 sec. A rather remote candidate for such a β ray is from the 683-msec positron decay of Sc^{42} formed in the $Ca^{40}(t, n)Sc^{42}$ reaction. Therefore, the experiment was repeated using 1.5-mg/cm²-thick KF and 1.1-mg/cm²-thick SrF_2 targets on steel backings. The results for the three targets are shown in Table I. The β branches to the first three states in Ne^{21} agree within the experimental uncertainties for the three targets. Hence, we are confident that the only important contaminant in the β-ray singles measurements is that due to the decay of F^{20}. The average of these measurements of the β branching to the first three states of Ne^{21} with the three targets is shown in the third column of Table II and the corresponding log*ft* values are given in the fourth column.

As mentioned above, a major purpose of this experiment was to search for a possible F^{21} β decay to the 2790-keV level in Ne^{21}. In order to maximize the low-energy β-ray counting efficiency, the bias on the β-ray detector was set as low as possible, and a γ-ray pulse height spectrum gated by β-γ coincidences was recorded. The resulting γ-ray spectrum shown in Fig. 2 gives no indication of a 2440-keV γ-ray which would indicate a β decay to the 2790-keV level, and leads to the upper limit on the β branch and corresponding lower limit on the log*ft* given in Table II.

Accurate measurements of the excitation energies of the first- and second-excited states were made by comparing the 350- and 1395-keV γ rays with known calibration sources.[10] Comparison of the γ-ray from the Ne^{21} first-excited state with the (302.79±0.10)-, (355.95±0.10)-, and (383.80±0.10)-keV lines from Ba^{133} led to a transition energy of 350.5±0.3 keV. An energy of 1395.1±0.3 keV for the γ-ray branch of the 1746-keV level to the 350-keV level in Ne^{21} was obtained from comparisons with the Na^{24} (1368.526±0.044)-keV γ ray, the two-escape peak of the (2614.47±0.10)-keV γ ray from ThC'', and the Co^{60}-(1332.49±0.04)-keV line.

TABLE II. β-ray branches in the decay of F^{21}.

Level in Ne^{21} (keV)	J^π	β Branch (%) Present work	log*ft* Present work	log*ft* Previous work
0	$\frac{3}{2}+$	29±6	5.23±0.10	4.8[a]
350.5±0.3[b]	$\frac{5}{2}+$	63±6	4.76±0.05	5.2[a]
1745.6±0.4[b]	$\frac{7}{2}+$	7.6±1.0	5.07±0.07	5.2[a]
2790.2±1.5[c]	$\frac{3}{2}$	<0.15	>6.0	...

[a] Reference 3.
[b] Present work.
[c] Reference 12.

The experimental results on the F^{21} β decay and Ne^{21} level energies from the present work are summarized in Fig. 3 and Tables I and II. In Fig. 3, the γ-ray branching ratios are from Ref. 11 and the energies of the triplet of states at $E_x \sim 2.8$ MeV are from Ref. 12. The spin and parity assignments are taken from the compilation in Ref. 11.

TABLE III. Comparison of experimental relative values of $(ft)^{-1}$ from the present work with those predicted by the strong-coupling model. F^{21} is taken to be pure $K=\frac{1}{2}$ while the first three states of Ne^{21} are assumed to be $K=\frac{3}{2}$.

Level in Ne^{21} (keV)	J^π	Relative value of $(ft)^{-1}$ (Present work)	Relative value[a] of $(ft)^{-1}$ predicted by strong-coupling model
0	$\frac{3}{2}+$	0.59±0.14	0.26
350.5	$\frac{5}{2}+$	1.75±0.21	1.75
1745.6	$\frac{7}{2}+$	0.85±0.15	1.83

[a] The theoretical $(ft)^{-1}$ value has been normalized to the experimental value at the 350-keV level.

DISCUSSION

The log*ft* values for the F^{21} β decay to the ground and first two excited states in Ne^{21} all indicate allowed transitions. This is consistent with the previously known spins and parities of the first three states of Ne^{21} [11] and the $J^\pi=\frac{5}{2}+$ assignment to the ground state of F^{21} which follows from Refs. 2, 3, and 13.

Kienle and Wien[2] were only able to set lower limits on the log*ft* values for F^{21} β decay to the first and second excited states of Ne^{21} of ≥ 5.0 and ≥ 5.2, respectively, since they did not measure the relative ground-state branch. These limits on the log*ft* values and their quoted uncertainty in the ratio of 1395- to 350-keV γ-ray intensities lead to a value of 0.15±0.07 for the intensity ratio of the β branch to the 1746-keV level relative to the branch to the 350-keV level which is consistent with the corresponding ratio of 0.12±0.02 measured in the present work. Their lower limits on the log*ft* values for decays to the first and second excited states of

---

[10] Energies quoted for the calibration sources are from J. B. Marion [University of Maryland Technical Report No. 656, 1968 (unpublished)], except for the Ba^{133} energies which were from A. Schwarzschild (private communication).

[11] A. J. Howard, J. P. Allen, D. A. Bromley, J. W. Olness, and E. K. Warburton, Phys. Rev. **157**, 1022 (1967).

[12] J. G. Pronko (private communication).

[13] P. Horvat, Nucl. Phys. **52**, 410 (1964).

Ne^{21} of ≥ 5.0 and ≥ 5.2, respectively, are, however, inconsistent with our values of 4.76 ± 0.05 and 5.07 ± 0.07.

In Table II we have quoted the results of Bunker *et al.*,[3] which are in striking contrast with the present work. The discrepancy is made more graphic by comparison of the percent β branches measured in the present work with those implied by the log*ft* values from Ref. 3 of 73, 22, and 5% for the β transitions to the ground, first excited, and second excited states of Ne^{21}, respectively. The percentages of total F^{21} decays leaving Ne^{21} in the 1746-keV state measured in the two experiments probably agree within the uncertainties of both experiments. The relative β feeding of the ground and first excited states reported in Ref. 3 are, however, roughly the reverse of those reported in the present work.

The energy of the first excited state of 350.5 ± 0.3-keV measured in the present work is in excellent agreement with the value of 350.2 ± 0.8 keV quoted in Ref. 11. The value of 1745.6 ± 0.4 keV obtained in the present work is consistent with that of 1750 ± 7.0 keV given in Ref. 11 and disagrees slightly with a recent measurement of 1747.4 ± 1.0 from Ref. 12.

Our lower limit on the log*ft* for β decay to the 2790-keV level in Ne^{21} of ≥ 6.0 does not rule out an allowed transition and hence we cannot rule out a positive parity assignment to that level.

Bhatt[7] has successfully explained the fact that F^{17} and F^{21} have $J^{\pi} = \frac{5}{2}^+$ and $\frac{1}{2}^+$ ground and first excited states, respectively, while the order is reversed for F^{19}, by assuming a strong-coupling model description for these nuclei. In particular, these states are taken to be members of a $K = \frac{1}{2}$ rotational band, and in F^{21} some credence is given to this picture by the enhanced $E2$ decay of the first excited state.[14] Ne^{21} has also been described quite successfully within the framework of the strong-coupling model.[5] In particular, the first three states of Ne^{21} have been described in Ref. 5 as predominantly a $K = \frac{3}{2}$ rotational band with some $K = \frac{1}{2}$ and $\frac{5}{2}$ "contaminant" amplitude. Howard *et al.*[6] have shown that many properties of these three states are quite well explained by assuming them to be pure $K = \frac{3}{2}$. Since the deformation of Ne^{21} is characterized by $\eta \sim +4.0$[6] and that for F^{21} by $\eta \sim +2.0$,[7,14] and within the Nilsson model β-ray transition probabilities can be calculated only for initial and final states having the same deformation, we cannot compare the absolute log*ft* values measured here with ones predicted by the above models for the two nuclei. Under the assumption that the F^{21} ground state is a pure $K = \frac{1}{2}$ level and the first three states in Ne^{21} are in the same rotational band are are pure $K = \frac{3}{2}$ levels, we can compute the ratio of β moments for the decays to the first three states of Ne^{21}. Explicitly, the collective model predicts,[15] under these assumptions, for decays to states 1 and 2 in Ne^{21}

$$\left[\frac{(ft)_1}{(ft)_2}\right]^{-1}_{-1} = \left\{\frac{(\frac{5}{2}\,\frac{1}{2}\,11 \mid J^{(1)}\,\frac{3}{2})}{(\frac{5}{2}\,\frac{1}{2}\,11 \mid J^{(2)}\,\frac{3}{2})}\right\}^2,$$

where $J^{(1)}$ is the spin of state 1 and $(\frac{5}{2}\,\frac{1}{2}\,11 \mid J\,\frac{3}{2})$ is a vector-addition coefficient. Experimental values of $(ft)^{-1}$ are compared with those computed from the above relationship in Table III. The agreement is at best qualitative in that the β moment for the ground state is somewhat less than that for the first two excited states. Comparison with the experimental values given in column 3 of Table III reveals that the simple assumption of pure $K = \frac{3}{2}$ levels (column 4) for the first three states of Ne^{21} predicts that the ground-state moment is about a factor of 2 too low and the second excited state about a factor of 2 too high relative to the first excited state. According to Kelson and Levinson[5] the major contaminant amplitude in the first two excited states of Ne^{21} is from the $K = \frac{5}{2}$ band. Assuming $K = \frac{1}{2}$ for the F^{21} ground state, this $K = \frac{5}{2}$ contaminant amplitude won't contribute to the allowed Gamow-Teller β moments $(\Delta K = 2)$. Therefore, assuming the F^{21} ground state is pure $K = \frac{1}{2}$, the lack of good quantitative agreement in the $(ft)^{-1}$ values in Table III is apparently due to the small mixing of the $K = \frac{1}{2}$ band into the wave functions for the first three states of Ne^{21}.

ACKNOWLEDGMENTS

The authors are grateful to C. Z. Nawrocki and F. A. Mahnken for preparing all targets used in the present work.

---

[14] R. A. Mendelson, Jr., and R. T. Carpenter, Phys. Rev. **152**, 1002 (1966).

[15] G. Alaga, K. Alder, A. Bohr, and B. R. Mottelson, Kgl. Danske Videnskab. Selskab, Mat.-Fys. Medd. **29**, No. 9 (1955).