Beta-delayed proton and alpha emission in the decay of ^{17}Ne

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RADIOACTIVITY $^{17}\text{Ne}(\beta^+\text{p})$ and $(\beta^+\alpha)$ [from $\text{Mg}(\text{p},3\text{pxn})$ reaction]; measured $T_{1/2}$, β -delayed E_{p} , E_{α} , I_{p} , I_{α} , β -particle coincidences. ^{17}Ne deduced particle branching ratio, β strength function; compared with theory. MgO target, surface barrier Si detectors. On-line mass separation.

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Abstract:

The beta-delayed proton and alpha spectra from ^{17}Ne have been studied with Si-detectors. The Gamow-Teller strength in the decay of ^{17}Ne has been extracted and compared with a two particle-one hole shell model calculation. The experimental strength is quenched by a factor of 0.82 with respect to the calculated one. Furthermore, the decay scheme has been improved and is discussed in some detail. The proton-emitting levels in ^{17}F are very broad and the line shapes are strongly influenced by phase-space effects. Interference between peaks corresponding to the same intermediate spin is a prominent feature emerging clearly with the good resolution and statistics of the present work.

1 Introduction

The present paper is the third in a series, where the quenching of the axial-vector strength in nuclei is investigated by means of super-allowed beta-decays. The quenching of the axial-vector strength was first observed by Wilkinson [1] in an analysis of beta-decays in light nuclei. It has become more widely appreciated due to the work on (p,n) reactions in heavier nuclei [2], where the effect was shown to exist as well. Our approach to the problem has been to study the beta decays of very proton-rich light nuclei. In these decays a large part of the total Gamow-Teller strength is seen, so that the comparison with the theoretical models is less sensitive to details of the wave function: small shifts in the energies, cancellations etc. The nuclei investigated are, so far, ^{32}Ar [3] and ^{33}Ar [4], in both cases a quenching factor $(g'_A/g_A)^2$ close to one half was found giving an average factor of 0.54 ± 0.05 for the proton rich argon isotopes. Nevertheless, the quenching factor turns out to be very sensitive [5] to the exact theoretical model chosen.

This paper is concerned with the decay of ^{17}Ne , already studied in detail by Hardy et.al. [6], but the high intensities and clean beams at CERN's ISOLDE Facility have permitted many improvements, especially concerning the highly excited states in ^{17}F that are of special importance for the Gamow-Teller strength. As the decays of these states feed many levels in ^{16}O and ^{13}N it was necessary to reexamine the decay scheme in detail and to introduce some modifications. An unexpected finding made possible by the present high intensity data was the pronounced distortion due to interference of many lines.

Our motive for studying ^{17}Ne was that it is only three nucleons away from the double-magic nucleus ^{16}O . Theoretical calculations might therefore be more transparent and more reliable than in the case of the argon isotopes (see ref. [5] for a discussion of the isospin $T = \frac{3}{2}$ homologue ^{33}Ar). Excited states in the daughter nucleus, ^{17}F , are also well known from nuclear reaction data [7] and this allows a detailed interpretation of the experimental spectra in terms of known levels.

The present paper is organized as follows: Section 2 describes the experiment. The interpretation of the spectra and the decay scheme are given in section 3. The extraction of Gamow-Teller strength and the comparison with theory are given in section 4. The last section contains our conclusions.

2 The experiments

2.1 The set-up

The nuclide ^{17}Ne was produced at the ISOLDE facility at CERN in spallation reactions with a $1\ \mu\text{A}$ beam of 600 MeV protons from the Synchro-cyclotron impinging on a magnesium oxide target. The reaction products were extracted through a cooled line into a plasma ion-source; this assured chemical selectivity since only the noble gas neon could pass the line, while neighbouring elements were retained by condensation. The

Ne^+ beam from the ion source was accelerated to an energy of 60 keV and subsequently mass separated in the ISOLDE electromagnetic isotope separator [8]. The ion beam was finally directed to the measuring station by means of an external beam-line. To avoid pile-up in the detectors, the count rate was kept around 100 events per second (the optimum performance of this target and ion source combination at ISOLDE gives 5000 atoms/(s · μA) proton beam).

Table 1: Detector Characteristics.

Thickness (μm)	FWHM (keV)	$E_p^{\text{max}\dagger}$ (MeV)	$E_\alpha^{\text{max}\dagger}$ (MeV)	Spectra taken $\dagger$
1000	30	12 – 18	50 – 75	s,c s with small solid angle
27	45	1.5 – 2	6 – 9	s,c
15	38	0.9 – 1.5	4 – 6	s,c
10	80	0.7 – 0.9	3 – 4	s

$\dagger$ The ranges stem from the final solid angle.

$\dagger$ s = singles, c = coincidence, in close geometry unless stated.

The Ne^+ -beam was stopped in a 50 $\mu\text{g}/\text{cm}^2$ carbon foil placed between two detectors: an annular plastic scintillator in front of the foil (the beam passed through the central hole in the scintillator) and on the opposite side a Si surface barrier detector. The reflective covering of the scintillator was made thick enough to stop the recoiling nuclei that accompany the particle emissions. Several Si surface barrier detectors were used, their characteristics are given in Table 1. The data were accumulated with a VAX 11/750 using the GOOSY [9] data acquisition software, mainly developed at the GSI, Darmstadt.

Since the decay gives protons of energies higher than 10 MeV, it was necessary to use a 1000 μm thick Si detector for the main part (54 h) of the experiment. The singles spectrum shown in Figure 1 was taken in a small solid angle, about 0.2% of 4π sr, to avoid summing of the emitted particles with the preceding positrons. The coincidence and singles spectra from the close geometry (a solid angle about 30 %) were used to identify particles feeding the 6.05 MeV level in ^{16}O . The coincidence technique was also used to eliminate peaks from alpha contaminations.

The main peaks in the spectrum are numbered and the corresponding energies and intensities are given in Table 2. The energy calibration was done with proton lines from the decay of the well-known levels at 6.04 MeV, 8.43 MeV and the isobaric analogue state (IAS) at 11.19 MeV to levels in ^{16}O ; the energies of these transitions are known to better than 9 keV [7]. The resolution function of the detector was not unfolded from the spectra. Furthermore, pile-up was negligible at energies below 10 MeV.

Three thin detectors were used to study the low-energy particles in more detail. One motive for using a series of thin detectors was to utilize the different stopping powers

Figure 1:
Singles spectrum of β -delayed particles from ^{17}Ne measured with a 1000 μm thick Si detector (FWHM 30 keV at 5 MeV) at a small solid angle. Transition energies, absolute intensities and transition assignments of the numbered peaks are given in Table 2. The peaks marked α are from Rn-contaminations in the ISOLDE mass separator.

Table 2: Beta-delayed particles from ^{17}Ne . The 1000 μm detector.

Peak no. [†]	E (keV) ^{††}	Identification [†]
1	844 ± 10	p, 8.43 $\rightarrow$ 6.92
3	1312 ± 10	p, 8.08 $\rightarrow$ 6.05
4'	1651 ± 5	α , 8.08 $\rightarrow$ g.s. p, 8.43 $\rightarrow$ 6.05
6'	2039 ± 10	p, 10.0 $\rightarrow$ 7.12 α , 8.43 $\rightarrow$ g.s.
7	2229 ± 10	α , IAS $\rightarrow$ 2.36
8	2339 ± 8	p, 3.10 $\rightarrow$ g.s.
10'	2568 ± 20	p, 9.4 $\rightarrow$ 6.05/6.13 α , 9.4 $\rightarrow$ g.s.
11'	3265 ± 4	p, IAS $\rightarrow$ 7.12 α , 10.0 $\rightarrow$ g.s.
13	3763 ± 4	p, 4.65 $\rightarrow$ g.s.
16	4192 ± 4	p, IAS $\rightarrow$ 6.13
17	4276 ± 4	p, IAS $\rightarrow$ 6.05
18	4593 ± 4	p, 5.49 $\rightarrow$ g.s.
19	5115 ± 4	p, 6.04 $\rightarrow$ g.s.
20	7021 ± 5	p, 8.08 $\rightarrow$ g.s.
21	7370 ± 5	p, 8.43 $\rightarrow$ g.s.
22 ^a	≈ 7070	p, 8.2 $\rightarrow$ g.s.
23	8360 ± 40	p, 9.4 $\rightarrow$ g.s.
24	8820 ± 40	p, 10.0 $\rightarrow$ g.s.
25	9460 ± 20	p, 10.66 $\rightarrow$ g.s.
26	9720 ± 20	p, 10.9 $\rightarrow$ g.s.
27	9957 ± 4	p, IAS $\rightarrow$ g.s.
28	10880 ± 40	p, 12.25 $\rightarrow$ g.s.

[†] The primes mark composite peaks. See the text for the complete identification.

^{††} The energies are given in the laboratory frame. For the proton transitions going to the ground state of ^{16}O the excitation energy is:

$$E_{exc} = \frac{0.6005 \text{ MeV} + 1.06297 \cdot E}{1 - E/14899 \text{ MeV}}.$$

For α -transitions going to the ground state of ^{13}N the excitation energy is :

$$E_{exc} = \frac{5.8198 \text{ MeV} + 1.3027 \cdot E}{1 - E/12115 \text{ MeV}}.$$

[†] IAS denotes the isobaric analogue state in ^{17}F at 11.193 MeV.

^a This peak extends under peak 20 and 21 as the 8.2 MeV level is very broad.

Table 3: Beta-delayed particles from ^{17}Ne . The 10,15 and 27 μm detectors.

Peak no.	E (keV) [†]	Identification [†]
1	847 ± 20	p, 8.43 $\rightarrow$ 6.92
2	—	partially stopped protons from peak 3 and 4
3	1329 ± 20	p, 8.08 $\rightarrow$ 6.05 (and peak 4, partially stopped)
4	1655 ± 20	α , 8.08 $\rightarrow$ g.s. – double peak p, 8.43 $\rightarrow$ 6.05
5	1960 ± 15	α , 8.43 $\rightarrow$ g.s.
7	2252 ± 15	α , IAS $\rightarrow$ 2.36
9	2600 ± 50	edge in 10 μm , probably α -cutoff
10	2740 ± 40	α , 9.4 $\rightarrow$ g.s.
11	3255 ± 40	α , 10.0 $\rightarrow$ g.s.
12	3701 ± 40	α , 10.66 $\rightarrow$ g.s.
14	3920 ± 40	α , 10.91 $\rightarrow$ g.s.
15	4092 ± 20	α , IAS $\rightarrow$ g.s.
18	4350 - 4750	p, 5.49 $\rightarrow$ g.s. (tentative assignment)

[†] See the captions of Table 2.

of protons and alphas for the peak identification. The energy cutoffs can be found in Table 1. Calibrations of the thin detectors were made with alpha particles from ^{148}Gd , ^{239}Pu , ^{241}Am and ^{244}Cm . The energy calibration of the 10 μm detector was not very precise, since it was too thin to stop the 3.18 MeV alphas from ^{148}Gd completely. The main peaks in the spectra are given in Table 3 and a typical spectrum is shown in Figure 2. The large bump at low energy is due partly to beta particles and partly to high energy protons that pass through the detector.

2.2 The half-life

The half-life was measured with the technique described in ref. [4]. After a collection time of 0.2 s the number of proton decays as a function of time was monitored for 1.0 s; this measuring cycle was repeated until a total of $4.2 \cdot 10^4$ counts were accumulated. At the beginning of each cycle a ramp generator was started. Each proton event triggered the ramp generator to create a pulse with an amplitude proportional to the time elapsed from the start of the cycle. As none of the daughter nuclei in the decay of ^{17}Ne are precursors of beta-delayed proton or alpha emission this gives directly the decay curve for ^{17}Ne . The decay curve was fitted with an exponential function giving a half-life of

$$T_{1/2} = 109.3 \pm 0.6 \text{ms}$$

Figure 2:
Coincidence spectrum of β -delayed particles from ^{17}Ne measured with a Si surface barrier detector of thickness $27\text{ }\mu\text{m}$. The coincidence requirement was the detection of a beta in an annular plastic scintillator placed upstream from the collection point. The identification of the peaks is given in Table 3.

with a χ^2 of 36.8 for 34 degrees of freedom. This is in perfect agreement with the previously measured value [6] of 109.0 ± 1.0 ms.

3 The decay scheme

3.1 Identification of lines

The nuclei in the decay chain are well known from reaction studies, which means that the interpretation of the spectra can be based on known levels. The levels that are populated are shown in Figure 3. Beta-delayed proton emission and beta-delayed alpha emission take place to levels in ^{16}O and ^{13}N , respectively. Some of the levels fed in particle decays are again unbound, so that emission of secondary particles to the ground state of ^{12}C can occur.

Essentially all peaks above 3 MeV in Figure 1 correspond to proton branches to the ground state in ^{16}O . The only exceptions are branches from the IAS to excited states in ^{16}O , easily identifiable by their small widths. To identify the lines below 3 MeV we use the spectra obtained with the thin detectors. Our assignments are given in Tables 2 and 3. Three new levels have been assigned to ^{17}F , all of them seen in more than one decay channel; they are marked with dashed lines in Figure 3 and have excitation energies of 9450 ± 50 keV, 10030 ± 50 keV and 10660 ± 20 keV and widths of 200 ± 40 keV, 170 ± 40 keV and 90 ± 60 keV, respectively. The broad level seen [7] at 8.2 MeV in ^{17}F is strongly affected by interference with other spin $3/2^-$ levels, the extraction of its parameters is discussed in subsection 3.3. The region between peak 4 and peak 13 (Figure 1) contains several proton lines; it is difficult to assess the contents of these lines, as they are not seen in the thin detectors and as the background, from tails of higher energy lines, is not known accurately. We assume peak 7 to be a pure alpha line and can estimate the contents of it in Figure 1 by scaling its intensity as seen in the thin detectors. From this, one can estimate the background under the peak and get the approximate intensities of the adjacent peaks.

Peak 4 is a doublet, the two transitions correspond to an alpha branch from the 8.08 MeV level to the ground state of ^{13}N and a proton branch from the 8.43 MeV level to the 6.05 MeV level in ^{16}O . The protons from this peak and from peak 3 are only partially stopped in the thin detectors. They have, however, lost an appreciable fraction of their energy and can be seen as the bump named peak 2 (Figure 2). From the variation of the intensity of peak 4 in different detectors and correcting for the effect of the decay of the 6.05 MeV level (see the next paragraph), we find the intensity of the alpha branch and the proton branch to be approximately equal. The uncertainty is large, we therefore take the ratio of protons to alphas to be 1.0 ± 0.5 .

The 6.05 MeV state in ^{16}O decays by emission of an electron-positron pair and branches to this state are therefore easily identifiable [6]. The emitted pair will increase our coincidence efficiencies and lead to summing in both coincidence and singles spectra in the close geometry; if uncorrected, this would lead to distortion of the extracted

Figure 3:

Decay scheme of ^{17}Ne . The level energies are taken from recent compilations [7] for the known levels (solid lines), the three new levels are marked with dashed lines. Apart from the two lowest levels, only levels with spin $1/2^-$ or $3/2^-$ are shown in ^{17}F . The left hand side shows the alpha branches, the right hand side the proton branches.

Table 4: Branching ratios in the decay of ^{17}Ne .

$E(^{17}\text{F})$ MeV	J^π	Total branching ratio, %		Decay branches [†]
		This work	Ref. 6	
0.0	$5/2^+$	0.53 ± 0.16^a		
0.495	$1/2^+$	0.76 ± 0.13^a		
3.10	$1/2^-$	$0.10 \pm^{+0.03}_{-0.01}$	0.48 ± 0.07	p_0
4.65	$3/2^-$	16.54 ± 0.14	16.2 ± 0.7	p_0
5.49	$3/2^-$	59.16 ± 0.4	54.4 ± 0.7^b	p_0
6.04	$1/2^-$	7.8 ± 0.2	10.6 ± 0.2	p_0
8.08	$3/2^-$	7.3 ± 0.9	6.83 ± 0.11	p_0, p_1, α_0
8.2	$3/2^-$	1.7 ± 0.3	2.08 ± 0.08^b	p_0
8.43	$1/2^-$	4.0 ± 0.9	6.51 ± 0.26	p_0, p_1, p_3, α_0
9.4	—	0.6 ± 0.2	—	$p_0, p_1/p_2, \alpha_0$
10.0	—	0.7 ± 0.3	—	p_0, p_4, α_0
10.66	—	0.007 ± 0.004	—	p_0, α_0
10.9	$1/2^-$	0.016 ± 0.006	—	p_0, α_0
11.193	$1/2^-$	0.64 ± 0.14^c	$0.71 \pm^{+0.1}_{-0.05}$	$p_0, p_1, p_2, p_4, \alpha_0, \alpha_1$
12.23	—	0.001 ± 0.0006	—	p_0

[†] The notation in Figure 3 is used to indicate which particle decay branches are identified in our spectra.

^a Calculated, from refs 6 and 10.

^b Obtained by adding several of the peaks in ref. 6.

^c Including the γ -branch, see the text.

strength. The enhanced coincidence efficiency is clearly visible in Figure 4 for peaks 2, 3 (the 15 μm detector) and 17 (the 1000 μm detector). The latter peak cannot be seen above the background in the singles spectrum, but is evidently smaller than in the coincidence spectrum. A sum peak built on peak 17 should be present in both spectra; it cannot be separated from the tail of peak 18, but it leads to a decreased peak size compared to the spectrum measured with a small solid angle. The effects of summing could also be seen for the proton component of peak 4 in close geometry.

3.2 The decay scheme

The two lowest levels in ^{17}F are particle-stable and cannot be observed in the present experiment. We adopt the values for the branching ratios calculated in refs [6,10]: 0.53 ± 0.16 % to the ground state and 0.76 ± 0.13 % to the first excited state. This gives a total branching ratio for particle decay of 98.7 ± 0.3 % so that the correction of the measured particle branching ratios is small and should be accurate. To compare

Figure 4:

Singles (dashed line) and beta-coincident (full line) spectra from the 15 μm detector. Only the low energy lines are shown, the peak numbers correspond to the ones given in Figure 2. The spectra have been rescaled to ease comparison. Note the enhancement of peaks 2 and 3 in the coincidence spectrum. The inset shows the peaks corresponding to decays from the IAS to the 6.05 and 6.13 MeV levels in ^{16}O as measured in the 1000 μm detector in close geometry. The full line is from the coincidence spectrum, the dashed line from the singles spectrum. See the text for discussion.

the spectra from different detectors the peaks seen in more than one of them are used for normalization. The total branching ratios for beta decay to the levels in ^{17}F are given in Table 4.

The major transitions in our decay scheme agree well with the earlier experiment [6], the results of which are included in Table 4 to facilitate comparison. In the present work, the structure in the proton spectrum between 5 MeV and 8 MeV is interpreted differently, so that the peaks at 6.406 MeV, 7.708 MeV and 8.825 MeV reported in ref. [6] are not confirmed here. The structures corresponding to the last two assignments stem from the broad level at 8.2 MeV, while we interpret the first structure as an (presumably enhanced, see next subsection) extended tail rather than a peak. The branch from the IAS to the 6.92 MeV level in ^{16}O is not observed here, our upper limit is 35 % of the p_0 -branch from the IAS.

Concerning the intensities, the main differences occur for the level at 3.10 MeV and for the decay of the IAS. The protons from the 3.10 MeV level (peak 8) are situated on a background of other lines; in ref. [6] this background was included in the peak. The same arguments apply to peak 11, i.e. the protons from the IAS to the 7.12 MeV level in ^{16}O . The experiments do also differ on the branch from the IAS to the 6.05 MeV level in ^{16}O . This branch has not been observed directly before, and our value for the branching ratio is much larger than the limit given in ref. [6] and from proton scattering experiments [11]. Our identification is supported by two observations: first the peak is well resolved in our spectrum, and second the coincidence efficiencies behave as expected for a level that decays by pair production (see Figure 4).

To obtain the total experimental branching ratio of the isobaric analogue state, we include the γ -branch [12] to the 0.50 MeV level in ^{17}F . Its width, Γ_γ , can be converted to an equivalent number of counts by using the measured [13] width of the branch to the ground state in ^{16}O , $\Gamma_{p_0} = 19 \pm 3$ eV. The decay of the IAS is summarized in Table 5 under the assumption that all particle decays are seen here. As discussed in ref. [6], the branches to higher excited states in ^{16}O and ^{13}N are expected to be small; the limits on these branches from our data are 4 – 5 % for each transition. Our ground state branching ratio, $\Gamma_{p_0}/\Gamma = 10.7 \pm 0.6$ %, is consistent with the directly measured value [14] of 8.8 ± 1.6 %. Furthermore, from the upper limits on unseen branches we get a lower limit of 9 % on this ratio. There are no other levels for which our data and reaction data [7] overlap sufficiently to allow comparisons to be made.

A new feature in the present study is the identification of the alpha branches that total 2.7 ± 0.9 % of the decays. A small contribution of secondary protons coming from the 2.36 MeV level in ^{13}N (this level is fed by the IAS) should also be present in our spectra. They will, however, lie at very low energies and will furthermore be strongly recoil-broadened; they could therefore not be uniquely identified. We cannot be certain to have identified all decay branches, e.g., a direct three-body break-up into $^{12}\text{C} + p + \alpha$ would not give a clear signature. In the special case of the IAS we can get a limit on unobserved branches. From our extracted Γ_{p_0}/Γ ratio and the directly measured one the intensity of possible additional branches is 21 ± 23 %, i.e. compatible with zero within the fairly large error.

Table 5: Decay of the IAS in ^{17}F .

Emitted particle	Final state (MeV)	Branching ratio, % This work	Ref. 7
p	^{16}O g.s.	10.7 ± 0.6	9.3 ± 1.3
	6.05	11 ± 3	< 3
	6.13	25 ± 2	22 ± 2
	6.92	< 4	24 ± 6
	7.12	18 ± 3	44 ± 4
α	^{13}N g.s.	1.1 ± 0.5	} < 7
	2.36	29 ± 9	
γ	^{17}F 0.50	3.4 ± 1.5^a	

^a From refs 12 and 13.

3.3 The line shapes

The large Q-value (14.53 MeV) of ^{17}Ne and its relatively small mass means that the effects of recoil will be visible. The "secondary" protons from ^{13}N will of course exhibit large recoil shifts and recoil broadenings, but even the beta-recoil is noticeable at our level of resolution. The beta-recoil shifts, as calculated from ref. [15], are typically 10 keV. This is consistent with experiment.

A striking feature in our spectra is the strong effects of interference, identified here for the first time. It is clearly present in the energy region from 3 to 8 MeV, reproduced in more detail in Figure 5. Several of the levels populated in ^{17}F are so broad that they overlap. Interference will then take place for decays leading to the same final states, in our case between levels in ^{17}F with the same spin and parity. In the proton spectrum the $3/2^-$ levels at 4.65 MeV and 5.49 MeV and the levels at 8.08 MeV and 8.2 MeV clearly interfere. As the spin of the broad 8.2 MeV level is known to be $3/2$, the presence of interference means that the 8.08 MeV level must have spin $3/2$. The absence of interference for the 8.43 MeV level and the spin $1/2$ of ^{17}Ne leads to spin $1/2$ for the former. All the levels have negative parity as the beta decay is allowed.

The spectral shape including interference effects can be calculated from R-matrix theory as done [16,17] for the mass-8 systems. The situation is here not as simple as for mass 8, as we have several open decay channels for the highest group of interfering levels. This complicates the calculations. We have not attempted a fit of the data, but as an illustration show in Figure 6 the upper group of levels together with the spectrum obtained from a one-channel approximation for two interfering states. The shape is in this case given by equation (9) in Warburton's paper [17] to which we refer for a detailed discussion. The dashed line is calculated from Warburton's equation (9), the dotted line

Figure 5:

The energy region from 3 to 8 MeV (energy in laboratory frame) in the proton spectrum, here taken from the coincidence spectrum of the 1000 μm thick detector in close geometry, shows strong interference between the $3/2^-$ levels. Destructive interference gives the dips at 4.2 MeV and 6.8 MeV, while constructive interference enhances the region around 5.5 MeV. The peaks from p_0 -transitions are marked with the spin of the levels in ^{17}F , the peaks from transitions to excited states in ^{16}O are marked with stars.

Figure 6:

The high-energy group from Figure 5 is here shown on a linear scale (the full line). To illustrate the effects of interference two calculated curves are shown, the dashed line giving the result including interference and the dotted line the results without interference. The $\frac{1}{2}^-$ level is not affected by the interference and has therefore not been included in the calculated curves. All spectra were normalized to give the same peak intensity.

shows the shape obtained with the same parameters but without interference: each level being treated as if it was an isolated resonance and the resulting intensities simply added. (The parameters used are the following: $E_1 = 8.075$ MeV, $\gamma_1 = 0.18$, $E_2 = 7.75$ MeV, $\gamma_2 = 0.40$ and $M_{G2}/M_{G1} = 0.20$, where index 1 refers to the narrow 8.08 MeV level, index 2 to the broad level. The boundary condition parameter B was set to zero, so that the parameters are not simply related to physical observables.)

A similar simulation for the lower group of levels gave a result essentially identical to the experimental shape, and here again the two amplitudes were of the same sign. The two groups have the same spin and will thus interfere with each other, so that a detailed analysis must include all of the energy region of Figure 5 at one time. Rough estimates indicate that this interference between the two groups of levels is a major cause of the enhanced intensity above peak 19, which is much too pronounced to be due to a tail of peak 18 alone. Interference should also be expected between the 10.96 MeV level and the GT-component to the IAS, but no clear evidence for this is seen in the spectrum. No indication of interference was seen in the other decay channels. If the beta strengths are to be extracted with high accuracy one must correct for the effects of this interference (as done in [17]), this is not done here.

3.4 Comparison with the mirror decay

The feedings to the two lowest states in ^{17}F used in subsection 3.2 were calculated by comparing with the decay of ^{17}N to ^{17}O . The four lowest allowed transitions in the decays of ^{17}N and ^{17}Ne can, however, be compared experimentally [6,18], as done in Table 6. (The decay of ^{17}N has been compared with theory in ref. [19].) The corrections mentioned in subsection 4.1 have been included. The asymmetry as given by the δ -values defined in Table 6 tend to be positive giving relatively faster decays for $^{17}\text{N} \rightarrow ^{17}\text{O}$, the previous large negative value for the 3.10 MeV level is not confirmed. Note, however, that δ is smallest for the strongest transition.

Table 6: Comparison of mirror decays for mass 17.

Final state energy (MeV)		$(\text{ft})^+$	$(\text{ft})^{-\dagger}$	$\delta^\ddagger$
^{17}F	^{17}O			
3.10	3.06	$(1.3^{+0.2}_{-0.3}) \cdot 10^7$	$(1.2 \pm 0.2) \cdot 10^7$	0.1 ± 0.3
4.65	4.55	$(3.79 \pm 0.07) \cdot 10^4$	$(2.57 \pm 0.13) \cdot 10^4$	0.47 ± 0.08
5.49	5.39	$(6.51 \pm 0.12) \cdot 10^3$	$(7.2 \pm 0.3) \cdot 10^3$	-0.10 ± 0.04
6.04	5.95	$(3.53 \pm 0.11) \cdot 10^4$	$(2.24 \pm 0.16) \cdot 10^4$	0.58 ± 0.12

† Ref. 18.

$^\ddagger \delta = [(\text{ft})^+ / (\text{ft})^-] - 1$

As reviewed in ref. [20], large non-zero δ -values probably arise from the differences

in binding energies in the two decays. Calculations for $T = 1$ nuclei [20,21] are in good agreement with data, whereas the $T = 3/2$ nuclei so far seem more difficult to reproduce. One can compare with the situation for lighter nuclei [22] where small nucleon binding energies can give rise to drastic changes of the structure of a nucleus. If similar structural changes turn out to occur here, care must be taken in the interpretation of the strength function.

4 The Gamow-Teller strength

4.1 The experimental GT-strength

The Gamow-Teller strength, B_{GT} , is evaluated from the standard formula:

$$ft = \frac{K}{G_V^2 B_F + G_A^2 B_{GT}}$$

with the constants [23,24] $K/G_V^2 = 6141 \pm 4s$ and $(G_A/G_V)^2 = 1.59 \pm 0.01$. The radiative corrections to the Fermi decays have been taken out in the determination of the K/G_V^2 used here. The corresponding radiative corrections [25,23] to the Gamow-Teller transitions are 1 % for the lowest levels in ^{17}F increasing up to about 1.5 % at the isobaric analogue level. The lowest order correction, which is about 80 % of the total, is included in the f -values [26] we use. The remaining part is less than the experimental uncertainty in the f -factors and is neglected in the following.

The strength is, in general, found for each level using the branching ratios of Table 4. The Fermi strength B_F is assumed to be 3 for the IAS and zero for all the other levels. For the IAS the Γ_{p_0}/Γ ratio, taken either from this work or from Adelberger et.al. [14], is used together with our measured values for the p_0 branching ratio. The two different Γ -ratios give a B_{GT} to the IAS of 0.01 ± 0.14 and 0.41 ± 0.44 , respectively. The small values reflect, of course, that the beta transition to the IAS is entirely dominated by the Fermi contribution. We adopt the former value here, but note that if we missed some of the branches the strength would be underestimated. The same procedure is followed for the levels at 10.96 MeV and at 12.2 MeV with the branching ratios taken from ref. [7]. The non-unique identification of the 12.2 MeV level (a $3/2^-$ level exists at 12.25 MeV and a $1/2^-$ level at 12.355 MeV) adds to the uncertainty in this case. The uncertainty in the Q -value of 50 keV gives an uncertainty of 1 – 2 % in the f -values, which has been added. The amount of unobserved strength from protons going to the ground state in ^{16}O — from unobserved levels — is negligible. This is not the case for the branches to excited states; a rough estimate gives that unidentified lines at low energy originating from the levels between 8 and 11 MeV could give up to 0.2 units of strength. States above the IAS are not considered here.

A further correction must be taken into account for the broad level at 4.65 MeV. The variation of the beta decay phase space factor and the proton penetrability across this level can not be neglected. Even for a relatively narrow, low-lying level as the 6.04 MeV

level with a FWHM of 30 keV the variation of the phase space factor is a few percent. For the broad 4.65 MeV level the variation is large enough to change the extracted B_{GT} value by -3.4% ; the varying penetrability gives $+2.4\%$. As already stressed in ref. [17] this introduces an ambiguity in the interpretation of ft -values. They can be taken as a measure of the branching ratio to a level or as a measure of the Gamow-Teller strength (i.e. of the matrix element of the transition feeding the level).

The final results are shown in Figure 7 and after conversion to a strength function (B_{GT} per 0.25 MeV excitation energy bin) in the upper part of Figure 8.

4.2 Comparison with theory

For a comparison of the experimental features of the Gamow-Teller beta decay of ^{17}Ne into states of ^{17}F with a shell model prediction, the configuration-mixing model introduced in ref. [27] has been used to calculate the wave functions of the ground state of ^{17}Ne and of the $J^\pi; T = 1/2^-, 3/2^-; 1/2$ states and the $J^\pi; T = 1/2^-; 3/2$ isobaric analogue state of ^{17}F . The configuration mixing basis has been restricted to a two particle-one hole model space as in the recent calculation [28] of isovector magnetic quadrupole strengths in ^{17}O . The particle-particle matrix elements were obtained as in ref. [28] with the effective interaction of Shakin who solved the Bethe-Goldstone equation with the Yale free nucleon-nucleon potential. Matrix elements calculated with this interaction in the mass-16 system agree remarkably well with those quoted recently in ref. [29], which resulted from a solution of the Bethe-Goldstone equation using the Paris potential. For the determination of the particle-hole matrix elements the Millener-Kurath interaction [30] has been employed. Earlier attempts to predict the low-lying negative parity states of the mass-17 nuclei and the β -decay transition rates can be found in ref. [31].

The excitation energies of the $J^\pi = 1/2^-$ and $3/2^-$ states, the B_{GT} transition strengths and the $\log ft$ values of the present calculation (together with the $\log ft$ values of the earlier model predictions [31]) are summarized in Table 7 and are compared with experiment in Figure 7. Energies and wave functions were calculated for states up to about 13 MeV excitation energy corresponding to the highest observed levels. There is a fairly close correspondence of levels up to excitation energies $E_x \approx 6$ MeV. From there on the model predicts more negative parity states than experimentally detected. One should recall, however, that the states are already unbound from $E_x \approx 3$ MeV on and thus the weakly populated states might easily have escaped detection.

The comparison of the experimental and theoretical Gamow-Teller strength functions in Figures 7 and 8 shows that the observed trend of the β -decay strength is reproduced qualitatively well up to excitation energies $E_x \approx 12$ MeV. The total value of B_{GT} from theory is larger, however, than the one from experiment. As the uncertainty in the experimental strength is especially large for the IAS, due to the large Fermi-contribution in this transition, we have limited our comparison between the experimental strengths and the present shell model predictions to states below the IAS. This yields an overall quenching factor of $(g'_A/g_A)^2 = 0.82 \pm 0.07$ (with an uncertainty solely due to the experiment). The value of this reduction factor is closer to unity than values typically found

Figure 7:

Comparison between the experimentally observed and the theoretically calculated levels in ^{17}F reached through the Gamow-Teller β^+ decay of ^{17}Ne . The respective Gamow-Teller strengths are also given. The symbol IAS marks the isobaric analogue state.

Figure 8:

The figure shows the experimental Gamow-Teller strength function (upper part) compared with the calculated strength function (lower part). The possible range (0.01 – 0.41) of the strength to the IAS is indicated by the non-filled bar.

Table 7: Calculated excitation energies, B_{GT} values and log ft values of $J^\pi = 1/2^-$ and $3/2^-$ levels in ^{17}F .

	$E(^{17}\text{F}), \text{ MeV}$	B_{GT}	log ft	log ft [†]
$1/2^-$	3.01	0.03	4.94	6.11
	6.18	0.13	4.47	3.37
	9.68	0.51	3.88	6.67
	10.26	0.19	4.31	7.05
	11.00	0.10	4.58	
	11.24	0.18	4.33	
	13.27	0.07	4.74	
$3/2^-$	4.80	0.17	4.35	3.35
	5.34	0.55	3.84	4.85
	7.77	0.51	3.87	4.27
	7.94	0.11	4.54	5.95
	8.05	0.40	3.96	3.81
	8.55	$0.29 \cdot 10^{-3}$	7.12	3.41
	9.33	0.028	5.13	
	10.24	$0.27 \cdot 10^{-5}$	9.16	
	11.45	0.12	4.50	
	11.84	0.012	5.50	
	12.78	0.013	4.47	
	13.05	0.09	4.63	

[†] From ref. 31.

for Gamow-Teller beta decays in the sd-shell [32, 3–5], and more in line with the values for the p-shell [1,20]. Part of the quenching is certainly due to the limited configuration space used, in particular for the calculation of the ground state wave function of ^{17}Ne for which three particle-two hole components should be included. The possible structural effects alluded to in section 3.4 could also be felt, but seem to be on the 10 % level or smaller judged from the difference in strength in ^{17}Ne and ^{17}N . Mesonic and other subnuclear degrees of freedom have also been neglected.

In order to extract more information from the data we can look at the $1/2^- \rightarrow 1/2^-$ and $1/2^- \rightarrow 3/2^-$ transitions separately. The spins of the three new levels are not known, but by comparison with the number of levels of spin $1/2^-$ and $3/2^-$ in the model we can expect at most one of the levels to have spin $1/2^-$. The quenching factors for levels below the IAS of spin $1/2^-$ and $3/2^-$ will then lie in the ranges 0.50 – 0.85 and 0.80 – 1.00, respectively. The data indicate that the transitions to $1/2^-$ levels are more quenched or at least as

quenched as transitions to $3/2^-$ levels. If we assume that the proton pair in the sd-shell does not participate appreciably in the decay, we can compare with results for mass 15. Although not completely in agreement, both theory [33] and experiment [34] here find the $1/2^- \rightarrow 3/2^-$ transitions to be significantly more quenched than the $1/2^- \rightarrow 1/2^-$ transitions. We have no simple explanation to offer for this apparent difference in behaviour.

5 Conclusion

The decay scheme of ^{17}Ne has been revised on several points. Many of the minor decay branches have been identified including the alpha branches leading to ^{13}N . The decay of the isobaric analogue state has been studied in detail, our results differ from the ones obtained previously. The comparison between the experimental Gamow-Teller strength and the calculated one within a shell model approach yields an overall reduction factor $(g'_A/g_A)^2 = 0.82 \pm 0.07$ in line with similar values from Gamow-Teller beta decays of other p-shell nuclei. A separate evaluation of the strength in transitions to $1/2^-$ and $3/2^-$ levels seems to indicate a stronger quenching in the former ones, in contrast with the situation for mass 15 nuclei.

The mirror decay of ^{17}N to ^{17}O gives, where comparisons can be performed, larger strengths than the ^{17}Ne decay, which indicates that the wavefunctions in the two systems differ. This is not yet understood in detail, so we cannot be sure that our wavefunctions include this effect; in the worst case this could give a quenching of 10 % on top of the quenching present in neighbouring nuclei closer to stability.

Interference was found to affect the proton spectrum strongly although the effect on the total Gamow-Teller strength is small. We have at the moment only shown that the distortions of the shape can be understood qualitatively; it might be rewarding to attempt a more ambitious multi-level analysis of the proton spectrum.

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