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Distribution of log *ft* values for allowed , first and second forbidden beta transitions ($10 < A \leq 100$)

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Distribution of log *ft* values for allowed, first and second forbidden beta transitions ($10 < A \leq 100$)

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Abstract : The comparative β decay half-life, log *ft*, has been classified according to degree of forbiddenness for 2859 transitions between A = 11 - 100 nuclei. Results are given in different histograms, illustrating the empirical evidence for the range of each class. The survey suggests a reexamination of J^{π} assignment rules based on log *ft* values.

I. INTRODUCTION.

Precise determination of the beta decay rate in nuclei is the appropriate experimental approach in many current programmes, as :

- nuclear structure studies far from stability.
- tests of the weak vector current conservation.
- evaluation of the renormalization of G_A in complex nuclei.
- investigation of nuclear medium effects in first forbidden beta decay.

The experimental log *ft* values, which are linked to the forbiddenness of the beta transition, are found scattered on extensive ranges. Already with the limited number of cases in the first compilations, the difficulty to explain the distribution of these values has been brought out by E. Fermi : "... rigid classification of the empirical ft values seems hopeless"[1]. Raman and Gove[2] have evaluated and compiled a total of 160 log *ft* values from eight forbiddenness categories and have established a lower limit for each particular forbiddenness category. In consequence, it was possible to

assign, to a forbiddenness category of lower order, new transition of lower log *ft* values. These criterions have extensively been used in the evaluation of nuclear data by the International Network For Nuclear Structure Evaluation.

Since 1973, a considerable amount of additional data has been obtained and it was worthwhile to compile the existing results and check the validity of the empirical rules. In this work, a total of 2859 transitions has been classified. Data have been taken from the literature, from Nuclear Data Sheets[3] for A > 44, from Nuclear Physics A for lighter nuclei (ref. 4 for A = 21 - 44, ref. 5 for A = 18 - 20, ref. 6, 7 for A = 16 - 17, ref. 8 for A = 13 - 15 and from ref. 9 for A = 11 - 12) and from ref. 10.

TABLE I :

Different cases for β transitions ($A \leq 100$) and permissible range of log *ft* values [[a] for log f_0t , unless stated otherwise, ref. 2]

Class of transitions	Number of cases (this work)	Permissible range [a]
Allowed		
$\Delta J = 0, 1$, no parity change	2227	
$0^+ \rightarrow 0^+$, superallowed		
$0^+ \rightarrow 0^+$, isospin forbidden		> 6.4
First forbidden non unique		
$\Delta J = 0, 1$, parity change	424	>5.9 (log f_1t)
First forbidden unique		
$\Delta J = 2$, parity change	157	>8.5
Second forbidden non unique		
$\Delta J = 2$, no parity change	47	>11.0
Second forbidden unique		
$\Delta J = 3$, no parity change	4	> 12.8

In Table I, we have reported the different types of transitions which have been considered with the corresponding number of cases and the permissible range of log *ft* values resulting from the work of Raman and Gove[2]. These values gave the basis for spin and parity assignment (or limits) for a large number of states (parent or daughter).

In most cases, log *ft* values are accurate to ± 0.1. The special case of transitions from nuclei far from stability and populating high excited states must be taken with caution as uncertainties in beta decay energy may introduce large errors in log *ft* values. In recent years, an increase of sensitivity has been obtained for the measurement of weak β decay rates, mostly by using large Ge detectors. L-forbidden GT branches as low as 2.10^{-5} have been so reliably established (see for example ref. 11). In addition, nuclei far from stability have provided, through the detection of delayed charged particles, a sensitive means to study very weak β branches (as low as 10^{-7} for some delayed α)[12] in the decay of the precursor nuclide.

II. ALLOWED TRANSITIONS :

GENERAL CASE (ΔJ = 0, 1 ; no parity change).

For these transitions, the orbital momentum is unchanged and β–γ directional correlations are isotropic, thus evaluation of matrix elements (Fermi and GT) through beta decay rates are the only measurement which yields information on nuclear properties. The straggling of the experimental *ft* values is reported in Fig. 1. If we substract the peak corresponding to the superallowed transitions (log *ft* ≈ 3.5) the distribution of the data is close to the gaussian curve with the center at log *ft* = 5.56 and a width (FWHM) equal to 2.03. In Fig. 2a and Fig. 2b, these values are displayed separately for odd and even values of A and very similar distributions are found with the same mean value (log *ft* = 5.56) in both cases, but we observed a smaller width for odd nuclei.

The large number of transitions in this category includes various physical cases and it is of interest to consider different subsets :

- $0^+ \rightarrow 0^+$ transitions (isospin favored or hindered).
- transitions from even-even parent states.
- transitions from odd-odd parent states populating ground-states.
- transitions between mirror nuclei.

II.A. ALLOWED TRANSITIONS : $0^+ \rightarrow 0^+$ TRANSITIONS.

The transitions discussed here are pure Fermi. The corresponding values are reported in Table II and in Fig. 3 which displays the distribution for superallowed transitions between two members of an isobaric spin multiplet (peaks in the left-part of the figure) and the scattering of the values corresponding to isospin-forbidden transitions.

For the superallowed transitions, the two peaks at $\log ft = 3.18$ and 3.48 correspond respectively to $\Delta T = 0$ transitions between levels with $T = 2$ and $T = 1$. It must be noted that transitions of the first type have been observed in the decay of proton-rich nuclei (^{32}Ar, ^{20}Mg) but no measurement of their absolute value has been performed. This portion of the histogram remains therefore subject to further investigations.

On the contrary, transitions with $J^\pi = 0^+$ and $T = 1$ have been very accurately measured in order to determine the vector coupling constant G_V. A recent analysis[13] of the available data has obtained for 8 such transitions (^{14}O, $^{26}Al^m$, ^{34}Cl, $^{38}K^m$, ^{42}Sc, ^{46}V, ^{50}Mn and ^{54}Co) a mean value : $ft = 3044.78 \pm 2.51$ before correction for radiative and charge dependent effects.

Isospin hindered transitions correspond to situation where the Fermi matrix elements can be determined for beta transitions between members of two different isospin multiplets. This implies in general a change in isospin ($\Delta T \neq 0$) but not necessarily so. Such transitions were reviewed previously by Raman et al.[14] and the corresponding $\log ft$ values are important as the magnitude of the isospin impurities is directly related to the Fermi matrix elements. The admixture amplitude, α_T, of states of different T values and the effective Coulomb matrix element , $\langle V_{CD} \rangle$, can be deduced from the $\log ft$ values alone. In the previous compilation by Raman[14] only three isospin forbidden $0^+ \rightarrow 0^+$ transitions were reported for $A < 100$ with, in any case, $\log ft > 6.4$. If we omit the issue $^{58}Mn^m$, which will be discussed separately, we find 9 transitions in this category, the lower value been found for ^{70}Se : $\log ft = 6.4$ (see Table II). In the case of ^{66}Ge, for which a lower limit was given in ref. 14 ($\log ft > 6.59$), no $0^+ \rightarrow 0^+$ transition has been observed and the lower limit of 7.4 can be retained[15].

For $^{58}Mn^{m}$, the decay of the ($J^{\pi} = 0^{+}$) isomer[16,17] shows three beta transitions which are still very difficult to interpret. In particular, two $0^{+} \rightarrow 0^{+}$ transitions were reported with $\log ft = 4.9$ and 5.3. However these values have not been taken into account in Fig. 3 as possible γ feedings of the two 0^{+} levels (g.s. and 3244 keV) are not excluded[18].

II.B. ALLOWED TRANSITIONS. DECAY FROM EVEN-EVEN PARENT STATES.

This category is limited to $0^{+} \rightarrow 1^{+}$ transitions. For light nuclei, the (0^{+} , T) $\rightarrow$ (1^{+} , T-1) beta decay can be compared to the analogue M1 isovector gamma transition in the daughter nucleus[19]. The corresponding strength distribution is given in Fig. 4a. If we do not take into account the two particular cases found for A = 14 (^{14}O, $\log ft = 7.27$ and ^{14}C, $\log ft = 9.04$), explained by large configuration mixing in the ground state of these nuclei, the distribution is found centered around 4.83.

II.C. ALLOWED TRANSITIONS. DECAY FROM ODD-ODD PARENT STATES.

For allowed transtions, the category is limited to cases where odd proton and neutron are coupled to spin 1^{+}. These cases are found with a decay rate similar to the one of preceeding category (Fig. 4b).

II.D. ALLOWED TRANSITIONS : DECAY BETWEEN MIRROR NUCLEI.

The corresponding histogram (Fig. 5) displays clearly the two types of transitions observed in the decay of mirror nuclei :

- the transitions between analogue states, with a strong Fermi component ($\langle M_F \rangle^2 = 1$) to which a sizeable GT component may be superposed. The resulting strength is therefore located below $\log ft = 3.8$ (limit value for $\langle M_{GT} \rangle = 0$) as it can be seen in Fig. 5 where the dashed area corresponds to the transitions between analogue states. The GT component of the branch to the analogue states is directly related[20] to the magnetic moment μ and of particular interest to be compared to shell model estimates [21].

- the second type of transitions corresponds to the GT decay to the excited states in the daugther nucleus and its distribution (right portion of Fig. 5) reproduces the standard allowed GT distribution.

We note the weak decay branch from ^{27}Si (J^{π} = 5/2^{+}) to the 1014 keV level (J^{π} = 3/2^{+}) in ^{27}Al, observed with log *ft* = 7.3 ± 0.2. It is noteworthy that this branch, which is clearly outside the standard distribution, is also in sharp contrast with the sd shell model estimate[21] (log *ft* = 6.105).

III. FIRST FORBIDDEN ($\Delta J \leq 2$, parity change).

We discuss now transitions where the leptons are transporting orbital angular momentum. For light nuclei the first forbidden beta decay occurs near closed shells as can be seen in Fig. 6. Only two cases are found for A = 22 - 36 nuclei and these transitions in the ^{32}Cl decay were observed owing to the high sensitivity of delayed charged particles detection[12]. Recent shell model calculations[22-29], with different model spaces, allow now to use forbidden transitions in the prediction/experiment comparisons and extend our knowledge of nuclear structure in the region between major shells. For heavier nuclei, neutrons and protons are in different shells, often of opposite parity, and the clustering of forbidden transitions near closed shells disappears.

III.A. FIRST FORBIDDEN NON UNIQUE TRANSITION (ΔJ = 0, 1 ; parity change).

The corresponding transitions for A $\leq$ 100 are presented in Fig. 7. A few cases are located with log *ft* value < 5.9, which was the lower limit for this class indicated by Raman and Gove[2]. A brief discussion of these decays is appropriate and leads to distinguish different situations.

a. In some cases, values are reported with uncertainties related to experimental difficulties. In this respect, two branches would require further investigation :

The J^{π} = 1^{-}, E_X = 9.95 MeV state of ^{32}S, is reported[12] populated from the ^{32}Cl (J^{π} = 1^{+}) g.s. by a branch with log *ft* = 5.7 ± 0.1 In this experiment, absolute intensities for delayed particle groups have to be determined by normalization with a γ line to the well established γ decay[30]. The normalization may introduce an additionnal source of error.

The beta decay[31] of ^{97}Y, $J^{\pi} = 1/2^{-}$ to the ^{97}Zr , $J^{\pi} = 1/2^{+}$,with $\log ft = 5.66$ is below the limit for a forbidden β-branch and because of the difficulty to evaluate a ground state decay with accuracy, a confirmation of this value would be desirable.

b. A particular class of forbidden transitions is made up by $0^{+} \rightarrow 0^{-}$ and $0^{-} \rightarrow 0^{+}$ beta decays which are found very strong in many cases(^{16}N, ^{44}Ti, ^{50}K, ^{96}Y, ^{98}Y). The fastest reported in Fig. 7 is $^{16}N,0^{-} \rightarrow {}^{16}O,0^{+}$ with $\log ft = 3.79$. Such transitions are located near doubly magic nuclei where a strong overlap between pure spherical configurations may be found. These transitions are a potential source of information on the mesonic enhancement of M^{T} (time-like component of the axial current for these transitions of rank 0)[32].Their strength deduced from experiments, is also indicated by single-particle estimates.The need of a revision of the lower limit for first forbidden of this type was already asserted in 1988 by E.Warburton et al.[32].

c. Finally, a few cases are found with $\log ft$ in the 5.7-5.9 range, (^{17}N, ^{32}Cl, ^{74}Ga, ^{77}Sr, ^{79}Sr, $^{81}Ge^{m}$,^{91}Tc,^{93}Rb, ^{95}Ru) very close to the previous recommended lower limit.

III.B. FIRST FORBIDDEN UNIQUE TRANSITION

($\Delta J = 2$; parity change).

These transitions, have received a particular attention since the strong quenching of the decay rate is related to the repulsive nature of the T=1 particle-hole interaction[32,33,34].

The values (see Fig. 8 and Table III) are scattered in a $\log ft$ range exceeding the one reported in the previous compilation.These transitions, often reported with f_0 values (computed as if the transition were allowed) were reevaluated with $\log f_1 t$, as defined by Gove and Martin[35], in order to test the validity of previous rules. In Table III, both values ($\log f_1 t$ and $\log f_0 t$) are reported.

Values of $\log f_0$ and $\log f_1$ are tabulated between $E_{\beta} = 0$ and 10 MeV in ref. 35. They have been calculated from 10 to 25 MeV by Dessagne and Miehé[36].

The decay of $^{78}As(J^{\pi} = 2^{-})$ to ^{78}Se states at 2682 and 3295 keV decay[37] is clearly outside the range of first forbidden unique transitions

with $\log f_1 t = 7.29$ and 6.72, respectively, if we accept $J^\pi = 4^+$ for the two final states[38].

In the decays of ^{90}Rb and ^{98}Y, we find three $0^- \rightarrow 2^+$ transitions outside the accepted range (Table III). For the J^π assignement of the parent state, conflicting values are proposed[10,39-43]. Arguments recently given for a $J^\pi = 1^-$ assignment for both ground-states[10,42], would remove this discrepancy.

IV. SECOND FORBIDDEN NON UNIQUE TRANSITIONS.

($\Delta J = 2$; no parity change).

The number of transitions (Fig. 9) is small. Nevertheless it appears that many cases are found with log *ft* values much lower than the recommanded lower limit ($\log ft = 11.0$) given in ref. 2.

Conflicting results[44,45] are reported for the $6^+ \rightarrow 4^+$ (Ex = 4.627 MeV) transition in the decay of ^{52}Mn $\rightarrow$ ^{52}Cr where the spin assignment of the final state has to be confirmed.

The ^{55}V, $J^\pi = (7/2^-) \rightarrow E_X = 0.566$ MeV, $J^\pi = 3/2^-$ state in ^{55}Cr is not reported in Fig. 9 as a complete decay scheme is not yet available[46].

^{56}Co, $J^\pi = 4^+ \rightarrow$ ^{56}Fe is a very well known decay and therefore should give an interesting input in the present survey. The population of two 2^+ states ($E_X = 2.960$ and 3.370 keV) is reported[47] with log *ft* values respectively equal to 9.97 and 10.1, but examination of experimental data[48] allows only to give these numbers as lower limits.

The previously reported[16] $0^+ \rightarrow 2^+$ transition in ^{58}Mn decay has not been confirmed by a later study[17]. Likewise, the $J^\pi = 3/2^-$ ^{59}Cu decay to $J^\pi = 7/2^-$, $E_X = 1.338$ MeV level in ^{59}Ni, reported in ref. 49, with $\log ft = 7.19$, seems subject to confirmation, taking into account the discussion in ref.50.

The experimental evidence for a $3/2^- \rightarrow 7/2^-$ transition in ^{61}Cu decay[51,52] seems to allow only a lower limit, in contrast with the Nuclear Data Sheets evaluator conclusions[53]. For ^{65}Co, the $J^\pi = 7/2^-$ value for the parent state[53] and the intensity[16] to the $E_X = 0.694$ MeV, $J^\pi = 3/2^-$, final state are still to be validated. In the ^{65}Ga, $J^\pi = 3/2^-$, g.s. $\rightarrow$ ^{65}Zn decay, the J^π values for the 0.865 and 1.588 MeV are now well settled by (α, nγ) and (p, nγ) measurements[53] but beta branching ratios reported earlier[54]

were not measured with enough accuracy to assess the intensity of a $3/2^- \rightarrow 7/2^-$ transition.

In the $^{75}Se \rightarrow ^{75}As$ decay[55-58], we find a clear case where the different spin values are known and give an example of a $5/2^+ \rightarrow 9/2^+$ transition which would deserve a careful confirmation of the log *ft* value (7.77 ± 0.11)[59]. Again, in $^{97}Zr \rightarrow ^{97}Nb$, spin values are established but branches to $5/2^+$ are unrealistic (log *ft* = 8.4, E_x = 1.751 MeV and log *ft* = 8.0, E_x = 1.852 MeV)[60,61].

For the ^{77}Rb, $J^\pi = 3/2^- \rightarrow ^{77}Kr$ decay, a firm J^π assignment of the final state at 0.500 MeV [$J^\pi = (7/2^-)$] would be desirable. The same problem occurs for the final state in ^{83}Br, E_x = 0.799 MeV, populated in the $^{83}Se^m$, $J^\pi = 1/2^-$ decay[62]. In a number of cases, the parent J^π value is still dubious(^{88}Br, ^{95}Rh). For ^{88}Br, $J^\pi = (1^-)$ [63], appears unlikely with the β feeding of 3^- states[64].In the same way, proposed $J^\pi = (9/2)^+$ value for ^{91}Tc is in conflict with log *ft* = 7.23 transition to the E_x = 1.414 MeV state[65] in ^{91}Mo. Other similar situations are found with ^{93}Ru, $J^\pi = (9/2)^+$, ^{95}Rh, $J^\pi = (9/2)^+$, ^{97}Rb, $J^\pi = 3/2(+) \rightarrow ^{97}Sr$, $J^\pi = (7/2)^+$, $^{98}Nb^m$, $J^\pi = (5^+)$ and ^{100}Nb, $J^\pi = 1^+ \rightarrow ^{100}Mo$, $J^\pi = (3^+)$.

Cases which appear to have well established decay modes include : ^{91}Nb, $J^\pi = 9/2^+ \rightarrow ^{91}Zr$, $J^\pi = 5/2^+$ with log *ft* = 10.6

Finally, it appears that many second forbidden non unique transitions are reported in the literature, but none is found with log *ft* ≤ 10.5 which appears firmly established.

V. SECOND FORBIDDEN UNIQUE TRANSITIONS.

(ΔJ = 3 ; no parity change).

With very few cases observed, these decays are of interest for evaluation of an in-medium quenching of the spin operator and for comparison to similar properties in M3 γ transitions[66]. For 10 < A ≤ 100, five cases were reported in the previous survey[2] . The permissible range was given for log *ft* values, although log f_2t should be used. We find now four transitions (in Table IV) with log *ft* ≥ 12.7. The decay of ^{78}Ga, $J^\pi = (3^+) \rightarrow ^{78}Ge$, $J^\pi = 0^+$, E_x = 1.547 MeV is reported in ref. 38 but the evidence given in the experimental work[67] does not enable to give the intensity of this branch. A recent measurement[68] of β^+ decay of ^{54}Mn

gives for the 3^+ to 0^+ transition a lower limit ($\log ft = 14.1$) in agreement with previous results[2].

VI. SUMMARY.

In conclusion, the present investigation which takes into account the important increase of the input data (mainly from nuclei far from stability and from decays to high excited states) allows a revision of the accepted limits given previously[2] . The four rules proposed by S. Raman and N.B. Gove are recalled and compared to the results of the present survey :

<u>Rule 1</u> ; For Z< 80, if $\log ft < 5.9$, $\Delta J = 0,1$; $\Delta\pi = +$. If $3.6 < \log ft < 5.9$, and one of the states has $J^\pi = 0^+$, the other has $J^\pi = 1^+$.

In our lists with $Z < 50$, β transitions with $\log ft < 5.9$ are allowed with marginal exceptions. However, it is necessary to express two reservations:

- the rule does not include $0^+ \rightarrow 0^-$ and $0^- \rightarrow 0^+$ beta decays which cannot be distinguished from allowed transitions according their $\log ft$ values,
- it is necessary to shift slightly the limit (to $\log ft = 5.7$) in order to include presently known experimental data.

On the other hand, the previous isospin selection rule[2] which implies that $\log ft$ values in the 3.6-6.4 range are inaccessible to $0^+ \rightarrow 0^+$ decays, is fully confirmed with more cases (see Fig.3).

<u>Rule 2</u> ;If $\log f_1 t < 8.5$, $\Delta J = 0,1$; $\Delta\pi = \pm$.

From the survey, it appears that we need to set the limit at $\log f_1 t = 8.0$. A reexamination of the four cases (^{78}As, ^{90}Rb and ^{98}Y [2 transitions]) discussed before as first forbidden unique transition, may involve a further modification of this limit.

<u>Rule 3</u> ; If $\log ft < 11.0$, $\Delta J = 0,1$; $\Delta\pi = \pm$ or $\Delta J = 2$; $\Delta\pi = -$.

A number of cases discussed before suggests that the limit should be fixed near $\log ft = 10.6$ in order to include present data. The need of a

careful analysis of ^{75}Se and ^{97}Zr decays is clearly illustrated (Fig. 9) as values reported in this two cases are below the proposed limit.

<u>Rule 4 :</u> If log *ft* < 12.8, $\Delta J = 0,1,2$; $\Delta\pi = \pm$.

No exception have been found in the $A \leq 100$ range.

In this paper, the survey of 2859 beta transitions in the A = 11 to 100 range suggests some modifications of the previous empirical rules for log *ft* distribution values. Furthermore, a careful reexamination of many cases reported with low *ft* values and different degrees of forbiddenness, appears necessary. Most of these values are obtained from γ-spectroscopy measurements. They correspond to weak branching ratios (the transitions are unfavored) deduced from γ-imbalance. Different corrections (internal conversion, missing γ-rays or angular correlation measurements) may give considerable changes to these branching ratios.

A discussion of the displacement observed in this work for the mean value of these distributions as compared with those previously reported[69], would be of interest and is still to be done.

APPENDIX A Some Basic Numerical Values Used for Beta Matrix Elements Determination

In the last 20 years, changes in the values used for the vector and axial coupling constants, G_V and G_A, have induced changes in the beta decay matrix elements, even all other parameters (Q_β, half-life and branching ratios) being kept identical. We give here the recent values, found in the literature.

The beta transition probabilities are calculated as following :

$$ft = \frac{K}{G_V^{*2}\langle M_F\rangle^2 + G_A^2\langle M_{GT}\rangle^2} = \frac{k}{\langle M_F\rangle^2 + \left(\frac{G_A}{G_V}\right)^2\langle M_{GT}\rangle^2}$$

with $K = 2\pi^3 Ln2 \frac{h^7}{m_e^5 c^4} = 1.2306\,10^{-94}\ erg^2.cm^6.s$

where G_V and G_A are the vector and axial coupling constants

G_V* is the effective vector coupling constant which takes into account the radiative corrections and charge dependence effects

$\langle M_F \rangle$ and $\langle M_{GT} \rangle$ are the Fermi and Gamow-Teller matrix elements

Usually G_V* is given by the measurement of $0^+ \rightarrow 0^+$ decay rates and G_A / G_V from neutron decay correlations measurement. Different values of these coupling constants have been used in the literature during the two past decades.

* Raman et al. [70] (1975) :

$$ft = \frac{6177 \pm 4}{\langle M_F \rangle^2 + (1.251 \pm 0.009)^2 \langle M_{GT} \rangle^2}$$

* Wilkinson et al. [71] (1978) :

$$ft = \frac{6168 \pm 4}{\langle M_F \rangle^2 + (1.251 \pm 0.009)^2 \langle M_{GT} \rangle^2}$$

* Hardy et al. [72] (1990) :

$$ft = \frac{6147 \pm 7}{\langle M_F \rangle^2 + (1.260 \pm 0.003)^2 \langle M_{GT} \rangle^2}$$

* Wilkinson et al. [13] (1993) :

$$ft = \frac{6127 \pm 9}{\langle M_F \rangle^2 + (1.262 \pm 0.004)^2 \langle M_{GT} \rangle^2}$$

Remark : If we take the value from Review of Particle Properties[73] (1992), we find :

$$ft = \frac{5968.7 \pm 0.2}{\langle M_F \rangle^2 + (1.2573 \pm 0.0028)^2 \langle M_{GT} \rangle^2}$$

This k value is obtained in this case with $k = K / G_V$, instead of $k = K / G_V^*$.

It is interesting to include the case of the neutron decay where G_A / G_V has been carefully measured[74,75]. Indeed we can calculate the constant k knowing the neutron lifetime[73] ($T_{1/2} = 616.3 \pm 1.5$ s) and the phase space factor[76] ($f = 1.71465 \pm 0.00015$) :

$$k = ft\left[\langle M_F \rangle^2 + (1.2573)^2 \langle M_{GT} \rangle^2\right] = 6068 \pm 260$$

This value is in the range of the previous determinations.

In conclusion, we can say the the ratio G_A / G_V is well measured and does not evoluate. But, concerning the vector coupling constant, G_V, the published results show the need to choose a common value, even if this value should be modified by future experiments.

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TABLE II : $J^{\pi} = 0^{+} \rightarrow J^{\pi} = 0^{+}$ transitions
(superallowed and isospin forbidden), $A \leq 100$.

Initial nucleus	Final nucleus	log *ft*	Remark
^{20}Mg	^{20}Na	3.18	superallowed (T = 2 → T = 2)
^{32}Ar	^{32}Cl	3.18	"
^{14}O	^{14}N	3.489	superallowed (T = 1 → T = 1)
^{18}Ne	^{18}F	3.473	"
^{22}Mg	^{22}Na	3.477	"
^{26m}Al	^{26}Mg	3.482	"
^{26}Si	^{26}Al	3.48	"
^{30}S	^{30}P	3.482	"
^{34}Cl	^{34}S	3.484	"
^{34}Ar	^{34}Cl	3.484	"
^{38m}K	^{38}Ar	3.484	"
^{38}Ca	^{38}K	3.475	"
^{42}Sc	^{42}Ca	3.483	"
^{42}Ti	^{42}Sc	3.51	"
^{46}V	^{46}Ti	3.483	"
^{46}Cr	^{46}V	3.4	"
^{50}Mn	^{50}Cr	3.483	"
^{54}Co	^{54}Fe	3.484	"
^{62}Ga	^{62}Zn	3.49	"
^{58m}Mn	^{58}Fe	4.9	
^{70}Se	^{70}As	6.4	
^{64}Ga	^{64}Zn	6.513	
^{60}Mn	^{60}Fe	6.7	
^{42}Sc	^{42}Ca	6.78	
^{66}Ga	^{66}Zn	7.884	
^{78}Rb	^{78}Rb	7.93	
^{28}Mg	^{28}Al	7.96	
^{78}Rb	^{78}Rb	8.17	
^{66}Ga	^{66}Zn	8.39	

TABLE III : FIRST FORBIDDEN UNIQUE TRANSITION
($\Delta J = 2$, parity change).

Initial nucleus	Final nucleus	E_x (MeV)	$\log f_0 t$	$\log f_1 t$
^{11}Be (1/2$^+$)	^{11}B (5/2$^-$)	4.461	8.87	10.99
^{14}B (2$^-$)	^{14}C (0$^+$)	0.	6.88	10.20
^{16}N (2$^-$)	^{16}O (0$^+$)	0.	5.65	9.07
^{16}N (2$^-$)	^{16}O (0$^+$)	6.050	8.91	10.88
^{17}Ne (1/2$^-$)	^{17}F (5/2$^+$)	0.	7.10	9.81
^{17}N (1/2$^-$)	^{17}O (5/2$^+$)	0.	7.29	9.35
^{19}O (5/2$^+$)	^{19}F (1/2$^-$)	0.110	8.33	10.25
^{37}S (7/2$^-$)	^{37}Cl (3/2$^+$)	0.	7.53	9.32
^{38}S (0$^+$)	^{38}Cl (2$^-$)	0.	7.72	9.10
^{38}Cl (2$^-$)	^{38}Ar (0$^+$)	0.	7.42	9.21
^{39}Cl (3/2$^+$)	^{39}Ar (7/2$^-$)	0.	7.82	9.33
^{40}Cl (2$^-$)	^{40}Ar (0$^+$)	0.	7.62	9.75
^{40}Cl (2$^-$)	^{40}Ar (4$^+$)	2.890	7.92	9.66
^{41}Ar (7/2$^-$)	^{41}K (3/2$^+$)	0.	8.44	9.70
^{41}Ca (7/2$^-$)	^{41}K (3/2$^+$)	0.	10.71	10.53
^{42}K (2$^-$)	^{42}Ca (0$^+$)	0.	8.44	9.97
^{42}K (2$^-$)	^{42}Ca (0$^+$)	1.840	8.95	9.92
^{44}K (2$^-$)	^{44}Ca (0$^+$)	0.	7.71	9.62
^{44}K (2$^-$)	^{44}Ca (0$^+$)	1.880	8.30	9.88
^{44}K (2$^-$)	^{44}Ca (4$^+$)	2.280	8.47	9.97
^{45}K (3/2$^+$)	^{45}Ca (7/2$^-$)	0.	7.86	9.53
^{45}Ca (7/2$^-$)	^{45}Sc (3/2$^+$)	0.012	10.70	10.37
^{46}K (2$^-$)	^{46}Ca (4$^+$)	2.580	7.49	9.31
^{47}Ca (7/2$^-$)	^{47}Sc (3/2$^+$)	0.767	9.94	10.67
^{68}Cu (6$^-$)	^{68}Zn (4$^+$)	2.418	6.93	8.24
^{68}Cu (6$^-$)	^{68}Zn (4$^+$)	2.956	7.19	8.36
^{69}Zn (9/2$^+$)	^{69}Ga (5/2$^-$)	0.574	8.87	9.25
^{69}As (5/2$^-$)	^{69}Ge (9/2$^+$)	0.398	7.21	8.51
^{71}Zn (9/2$^+$)	^{71}Ga (5/2$^-$)	0.965	9.70	10.78

^{71}Zn (9/2$^+$)	^{71}Ga (5/2$^-$)	1.720	8.69	9.43
^{71}Se (5/2$^-$)	^{71}As (9/2$^+$)	1.000	7.91	9.26
^{72}As (2$^-$)	^{72}Ge (0$^+$)	0.	8.35	9.84
^{72}As (2$^-$)	^{72}Ge (0$^+$)	0.691	9.25	10.57
^{72}As (2$^-$)	^{72}Ge (4$^+$)	1.728	9.07	10.13
^{72}As (2$^-$)	^{72}Ge (4$^+$)	3.667	8.12	8.35
^{73}Se (9/2$^+$)	^{73}As (5/2$^-$)	0.067	7.69	8.78
^{74}As (2$^-$)	^{74}Ge (0$^+$)	0.	8.62	9.67
^{74}As (2$^-$)	^{74}Ge (4$^+$)	1.464	10.62	11.28
^{74}As (2$^-$)	^{74}Ge (0$^+$)	1.483	9.69	10.34
^{74}As (2$^-$)	^{74}Se (0$^+$)	0.	8.56	9.35
^{74}Br (4$^-$)	^{74}Se (2$^+$)	1.834	8.17	9.81
^{74}Br (4$^-$)	^{74}Se (6$^+$)	2.231	8.39	9.95
^{74}Br (4$^-$)	^{74}Se (2$^+$)	2.314	8.10	9.64
^{74}Br (4$^-$)	^{74}Se (2$^+$)	3.037	7.76	9.14
^{74}Br (4$^-$)	^{74}Se (2$^+$)	3.379	7.63	8.93
^{75}Zn (7/2$^+$)	^{75}Ga (3/2$^-$)	0.178	6.56	8.50
^{76}As (2$^-$)	^{76}Se (0$^+$)	0.	8.34	9.73
^{76}As (2$^-$)	^{76}Se (0$^+$)	1.122	9.76	10.29
^{76}As (2$^-$)	^{76}Se (4$^+$)	1.331	10.24	11.17
^{76}As (2$^-$)	^{76}Se (4$^+$)	2.026	10.48	11.00
^{76}As (2$^-$)	^{76}Se (0$^+$)	2.170	10.22	10.62
^{76}Rb (1$^-$)	^{76}Kr (3$^+$)	0.161	6.50	8.58
^{77}Ge (7/2$^+$)	^{77}As (3/2$^-$)	0.195	9.57	10.91
^{77}Ge (7/2$^+$)	^{77}As (3/2$^-$)	0.215	8.62	9.87
^{77}Ge (7/2$^+$)	^{77}As (3/2$^-$)	0.614	9.11	10.23
^{77}Ge (7/2$^+$)	^{77}As (3/2$^-$)	1.059	9.35	10.28
^{77}As (3/2$^-$)	^{77}Se (7/2$^+$)	0.521	8.32	8.44
^{77}Kr (5/2$^+$)	^{77}Br (1/2$^-$)	0.167	8.04	9.19
^{78}As (2$^-$)	^{78}Se (4$^+$)	0.	7.98	9.64
^{78}As (2$^-$)	^{78}Se (4$^+$)	1.499	9.20	10.51
^{78}As (2$^-$)	^{78}Se (4$^+$)	1.503	8.94	10.26
^{78}As (2$^-$)	^{78}Se (4$^+$)	2.682	6.42	7.29
^{78}As (2$^-$)	^{78}Se (4$^+$)	3.295	6.22	6.72
^{78}Rb (4$^-$)	^{78}Kr (2$^+$)	1.148	7.74	9.56
^{78}Rb (4$^-$)	^{78}Kr (2$^+$)	1.756	7.58	9.30

^{78}Rb (4$^-$)	^{78}Kr (6$^+$)	1.978	7.70	9.39
^{81}Kr (7/2$^+$)	^{81}Br (3/2$^-$)	0.	11.56	11.01
^{81}Sr (1/2$^-$)	^{81}Rb (5/2$^+$)	0.631	7.10	8.37
^{82}Br (2$^-$)	^{82}Kr (0$^+$)	0.	7.46	8.89
^{82}Br (2$^-$)	^{82}Kr (0$^+$)	1.488	9.46	10.40
^{82}Br (2$^-$)	^{82}Kr (0$^+$)	2.171	10.01	8.87
^{82}Br (2$^-$)	^{82}Kr (4$^+$)	2.556	8.24	8.42
^{83}Se (9/2$^+$)	^{83}Br (5/2$^-$)	0.357	7.95	9.42
^{83}Se (9/2$^+$)	^{83}Br (5/2$^-$)	0.799	7.85	9.21
^{83}Sr (7/2$^+$)	^{83}Rb (3/2$^-$)	0.389	8.36	9.35
^{83}Zr (1/2$^-$)	^{83}Y (5/2$^+$)	0.097	6.72	8.48
^{83}Zr (1/2$^-$)	^{83}Y (5/2$^+$)	0.332	7.02	8.75
^{84}Br (2$^-$)	^{84}Kr (0$^+$)	0.	7.23	9.47
^{84}Br (2$^-$)	^{84}Kr (0$^+$)	1.837	9.51	10.86
^{84}Rb (2$^-$)	^{84}Kr (0$^+$)	0.	8.39	9.51
^{84}Rb (2$^-$)	^{84}Sr (0$^+$)	0.	9.93	9.41
^{84}Y (5$^-$)	^{84}Sr (3$^+$)	2.055	7.65	9.27
^{85}Se (5/2$^+$)	^{85}Br (1/2$^-$)	1.191	7.73	9.54
^{85}Kr (9/2$^+$)	^{85}Rb (5/2$^-$)	0.	9.15	9.45
^{85}Y (9/2$^+$)	^{85}Sr (5/2$^-$)	0.785	8.16	9.28
^{85}Y (9/2$^+$)	^{85}Sr (5/2$^-$)	0.937	8.19	9.29
^{85}Zr (7/2$^+$)	^{85}Y (3/2$^-$)	0.637	7.57	9.00
^{86}Br (2$^-$)	^{86}Kr (0$^+$)	0.	7.50	9.65
^{86}Br (2$^-$)	^{86}Kr (4$^+$)	3.334	7.46	9.13
^{86}Rb (2$^-$)	^{86}Sr (0$^+$)	0.	8.45	9.44
^{86}Rb (2$^-$)	^{86}Kr (0$^+$)	0.	9.78	9.77
^{86}Y (4$^-$)	^{86}Sr (2$^+$)	1.077	8.84	10.30
^{86}Y (4$^-$)	^{86}Sr (2$^+$)	2.642	9.15	10.28
^{86}Y (4$^-$)	^{86}Sr (2$^+$)	2.788	8.95	10.06
^{87}Br (3/2$^-$)	^{87}Kr (7/2$^+$)	2.519	7.69	9.34
^{87}Zr (9/2$^+$)	^{87}Y (5/2$^-$)	0.794	8.55	9.74
^{88}Kr (0$^+$)	^{88}Rb (2$^-$)	0.	7.95	9.32
^{88}Kr (0$^+$)	^{88}Rb (2$^-$)	0.391	9.41	10.64
^{88}Kr (0$^+$)	^{88}Rb (2$^-$)	0.862	8.34	9.44
^{88}Kr (0$^+$)	^{88}Rb (2$^-$)	1.182	8.15	9.11
^{88}Kr (0$^+$)	^{88}Rb (2$^-$)	1.916	7.92	8.48

^{88}Rb (2$^-$)	^{88}Sr (0$^+$)	0.	7.38	9.24
^{88}Y (4$^-$)	^{88}Sr (2$^+$)	1.184	9.48	10.60
^{88}Y (4$^-$)	^{88}Sr (2$^+$)	3.219	9.68	9.44
^{89}Rb (3/2$^-$)	^{89}Sr (7/2$^+$)	1.473	8.76	10.16
^{89}Zr (5/2$^+$)	^{89}Y (1/2$^-$)	0.	8.42	8.99
^{90}Br (2$^-$)	^{90}Kr (0$^+$)	0.	6.68	9.12
^{90}Rb (0$^-$)	^{90}Sr (2$^+$)	0.832	7.34	9.26
^{90}Rb (0$^-$)	^{90}Sr (2$^+$)	1.8921	7.94	9.72
^{90}Rb (0$^-$)	^{90}Sr (2$^+$)	4.136	6.25	7.45
^{90}Sr (0$^+$)	^{90}Y (2$^-$)	0.	9.25	9.39
^{90}Y (2$^-$)	^{90}Zr (0$^+$)	0.	8.05	9.22
^{90}Y (2$^-$)	^{90}Zr (0$^+$)	1.761	9.55	9.65
^{90}Y (7$^+$)	^{90}Zr (5$^-$)	2.319	9.38	9.63
^{91}Y (1/2$^-$)	^{91}Zr (5/2$^+$)	0.	8.70	9.58
^{91}Nb (1/2$^-$)	^{91}Zr (5/2$^+$)	0.	8.44	9.28
^{91}Mo (9/2$^+$)	^{91}Nb (5/2$^-$)	1.187	8.81	10.09
^{91}Mo (9/2$^+$)	^{91}Nb (5/2$^-$)	1.845	8.16	9.34
^{92}Br (2$^-$)	^{92}Kr (0$^+$)	1.357	7.61	10.07
^{92}Y (2$^-$)	^{92}Zr (0$^+$)	0.	7.71	9.25
^{92}Y (2$^-$)	^{92}Zr (0$^+$)	1.383	8.37	9.53
^{92}Y (2$^-$)	^{92}Zr (4$^+$)	1.496	8.60	9.72
^{93}Y (1/2$^-$)	^{93}Zr (5/2$^+$)	0.	7.71	9.08
^{93}Zr (5/2$^+$)	^{93}Nb (1/2$^-$)	0.031	11.57	11.77
^{93}Mo (5/2$^+$)	^{93}Tc (1/2$^-$)	0.031	10.25	9.95
^{93}Ru (9/2$^+$)	^{93}Tc (13/2$^-$)	2.146	7.27	8.75
^{94}Y (2$^-$)	^{94}Zr (0$^+$)	0.	7.57	9.36
^{94}Y (2$^-$)	^{94}Zr (0$^+$)	1.300	8.51	10.12
^{94}Y (2$^-$)	^{94}Zr (4$^+$)	1.470	7.89	9.40
^{95}Sr (1/2$^+$)	^{95}Y (5/2$^-$)	0.827	7.72	9.57
^{95}Sr (1/2$^+$)	^{95}Y (5/2$^-$)	2.208	7.42	9.01
^{95}Y (1/2$^-$)	^{95}Zr (5/2$^+$)	0.	6.91	8.62
^{95}Zr (5/2$^+$)	^{95}Nb (1/2$^-$)	0.236	10.79	11.25
^{95}Nb (1/2$^-$)	^{95}Mo (5/2$^+$)	0.	8.52	9.21
^{95}Tc (1/2$^-$)	^{95}Mo (5/2$^+$)	0.	8.25	9.27
^{95}Tc (1/2$^-$)	^{95}Mo (5/2$^+$)	1.057	10.23	10.45
^{95}Tc (1/2$^-$)	^{95}Mo (5/2$^+$)	1.426	9.85	9.34

^{96}Y (0^-)	^{96}Zr (2^+)	1.751	6.74	8.61
^{96}Y (0^-)	^{96}Zr (2^+)	2.669	8.03	9.75
^{97}Ru ($5/2^+$)	^{97}Tc ($1/2^-$)	0.097	9.92	10.49
^{98}Sr (0^+)	^{98}Y (2^-)	0.496	7.20	9.06
^{98}Y (0^-)	^{98}Zr (2^+)	1.223	6.04	8.20
^{98}Y (0^-)	^{98}Zr (2^+)	1.591	5.81	7.92
^{98}Nb (5^+)	^{98}Mo (3^-)	2.420	8.00	9.17
^{98}Nb (5^+)	^{98}Mo (3^-)	2.485	8.17	9.31
^{98}Nb (5^+)	^{98}Mo (3^-)	3.209	7.90	8.74
^{99}Sr ($3/2^+$)	^{99}Y ($7/2^-$)	0.624	6.31	8.47
^{99}Sr ($3/2^+$)	^{99}Y ($7/2^-$)	0.818	6.48	8.63
^{99}Nb ($1/2^-$)	^{99}Mo ($5/2^+$)	0.098	7.72	9.25
^{99}Nb ($1/2^-$)	^{99}Mo ($5/2^+$)	0.615	7.87	9.27
^{99}Nb ($1/2^-$)	^{99}Mo ($5/2^+$)	0.945	7.33	8.64
^{99}Nb ($1/2^-$)	^{99}Mo ($5/2^+$)	1.354	7.28	8.46
^{99}Nb ($1/2^-$)	^{99}Mo ($5/2^+$)	1.483	6.99	8.12
^{99}Rh ($1/2^-$)	^{99}Ru ($5/2^+$)	0.	7.98	9.11
^{99}Rh ($1/2^-$)	^{99}Ru ($5/2^+$)	0.576	9.23	10.16
^{99}Rh ($1/2^-$)	^{99}Ru ($5/2^+$)	0.734	9.21	10.05
^{100}Nb (1^+)	^{100}Mo (3^-)	3.004	6.55	8.01

TABLE III : SECOND FORBIDDEN UNIQUE TRANSITION
($\Delta J = 3$, no parity change).

Initial nucleus	Final nucleus	E_x (MeV)	$\log f_0 t$
^{22}Na (3^+)	^{22}Ne (0^+)	0.	12.73
^{26}Al (5^+)	^{26}Al (2^+)	1.810	14.18
^{26}Al (5^+)	^{26}Al (2^+)	2.940	14.18
^{60}Co (5^+)	^{60}Ni (2^+)	1.332	15.03

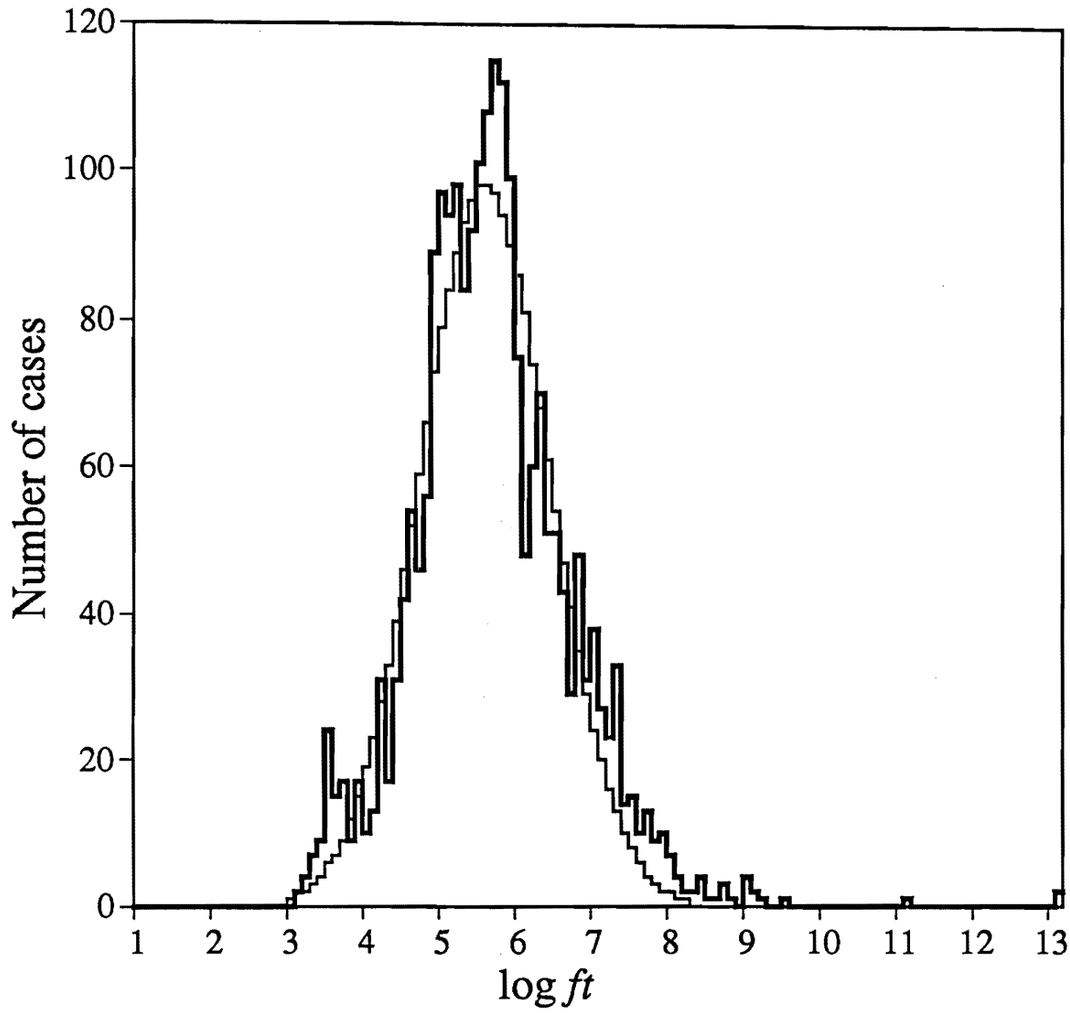

Fig. 1. Histogram of the frequency of log *ft* values (thick line) for allowed β transitions ($10 < A \leq 100$) and the corresponding fitted gaussian distribution (thin line) is centered at 5.56 with fwhm = 2.03.

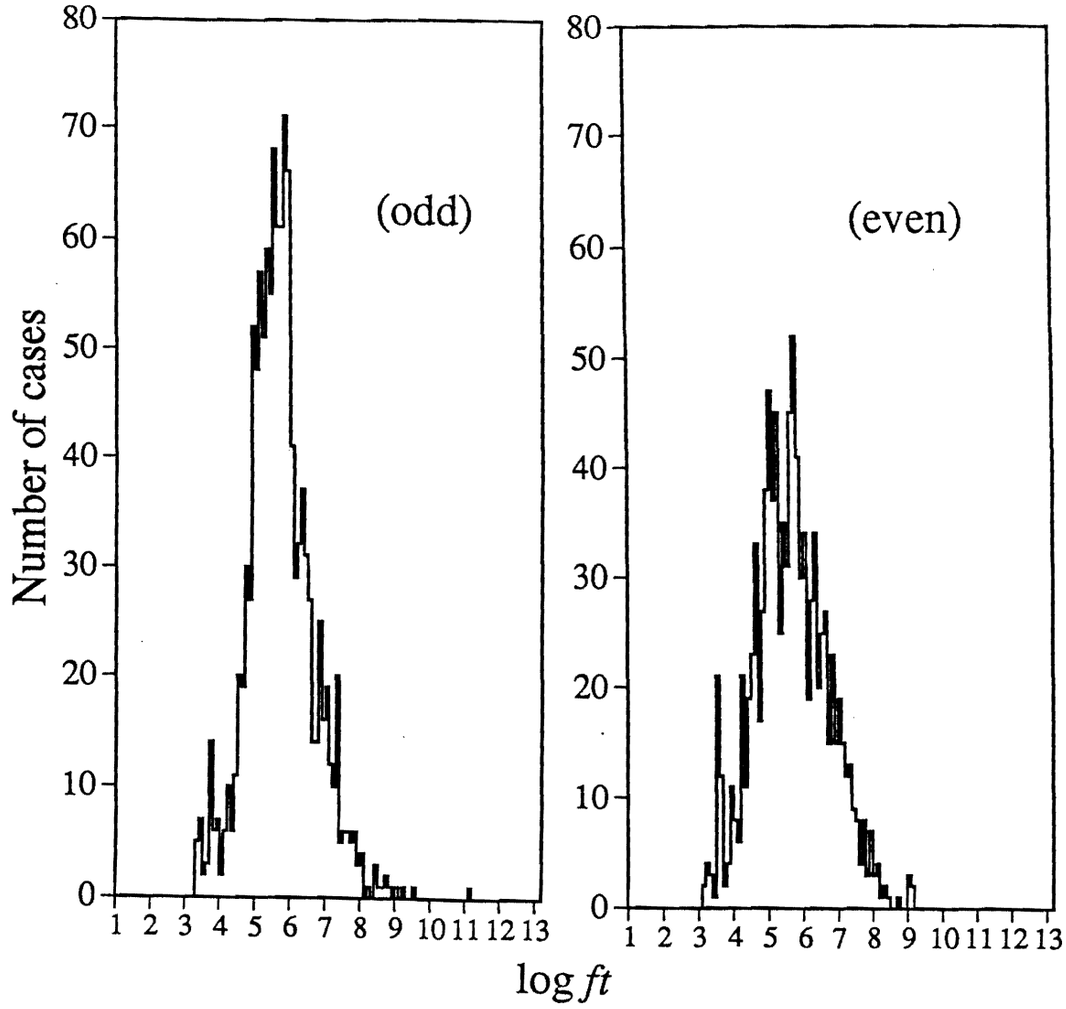

Fig. 2. Frequency distribution of log *ft* values for allowed β transitions for odd and even values of A ($10 < A \leq 100$). Mean values in both cases are located at 5.56.

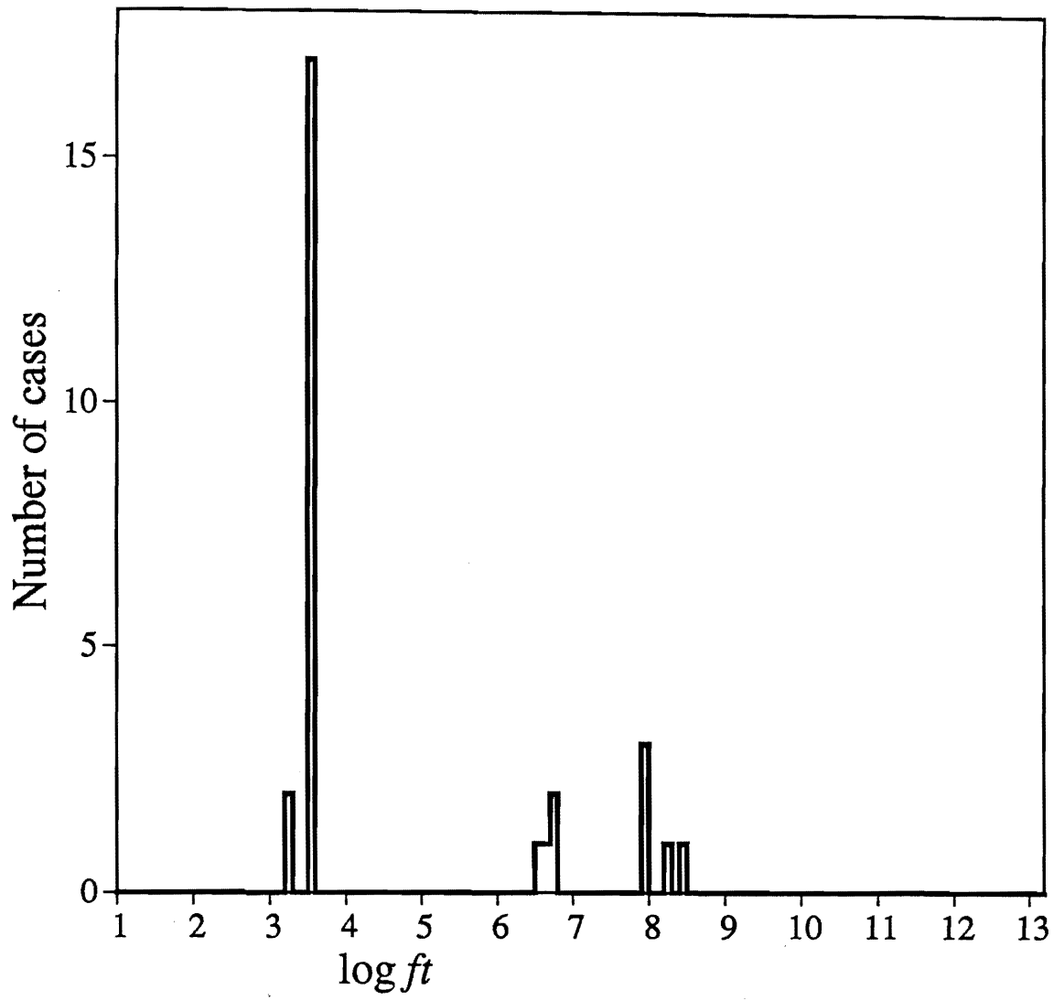

Fig. 3. Frequency distribution of log *ft* values for $0^+ \rightarrow 0^+$ β transitions ($10 < A \leq 100$). These transitions are included in those reported in Fig. 1. The two classes of transitions (superallowed and isospin forbidden) are clearly separated by the 3.6 - 6.4 range of log *ft* values.

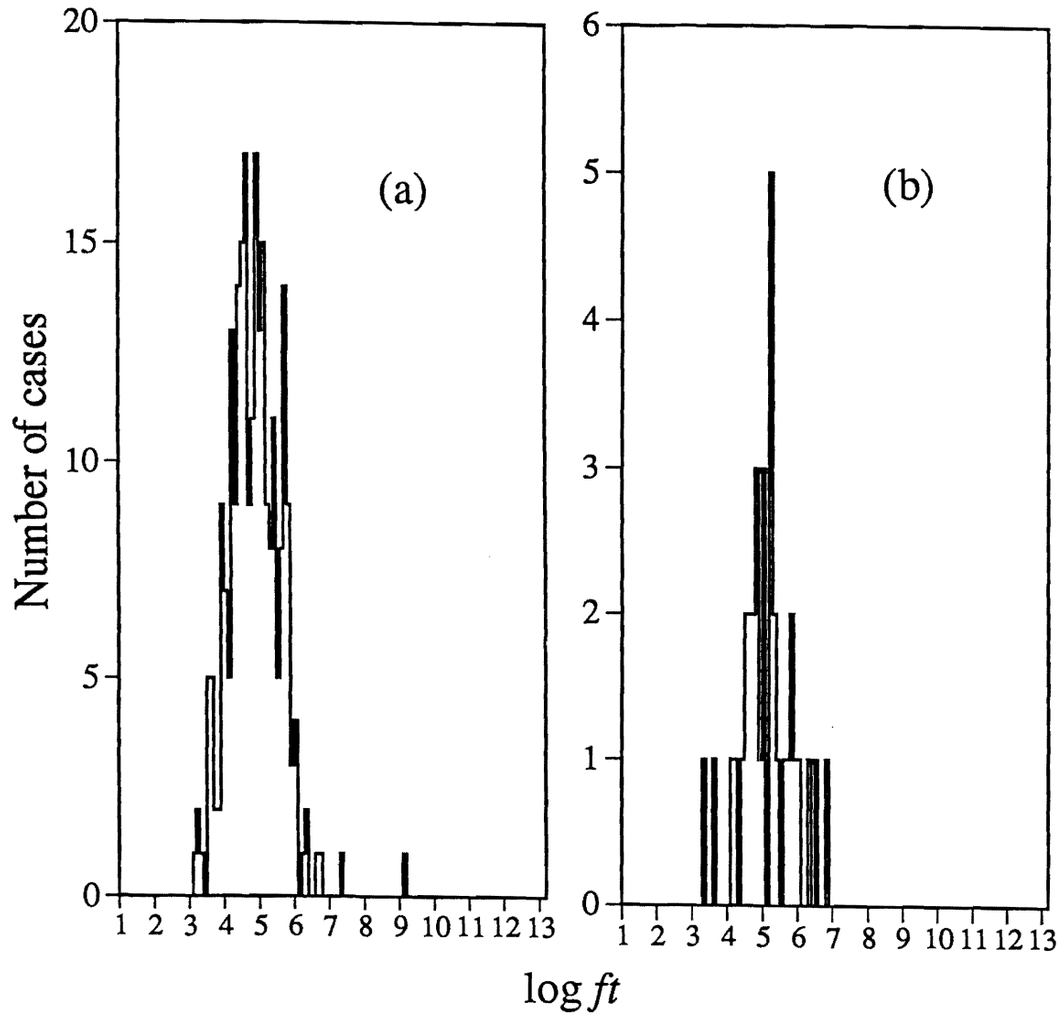

Fig. 4. Frequency distribution of log *ft* values for (a) $0^+ \rightarrow 1^+$ β transitions and for (b) $1^+ \rightarrow 0^+$ g.s. β transitions ($10 < A \leq 100$).

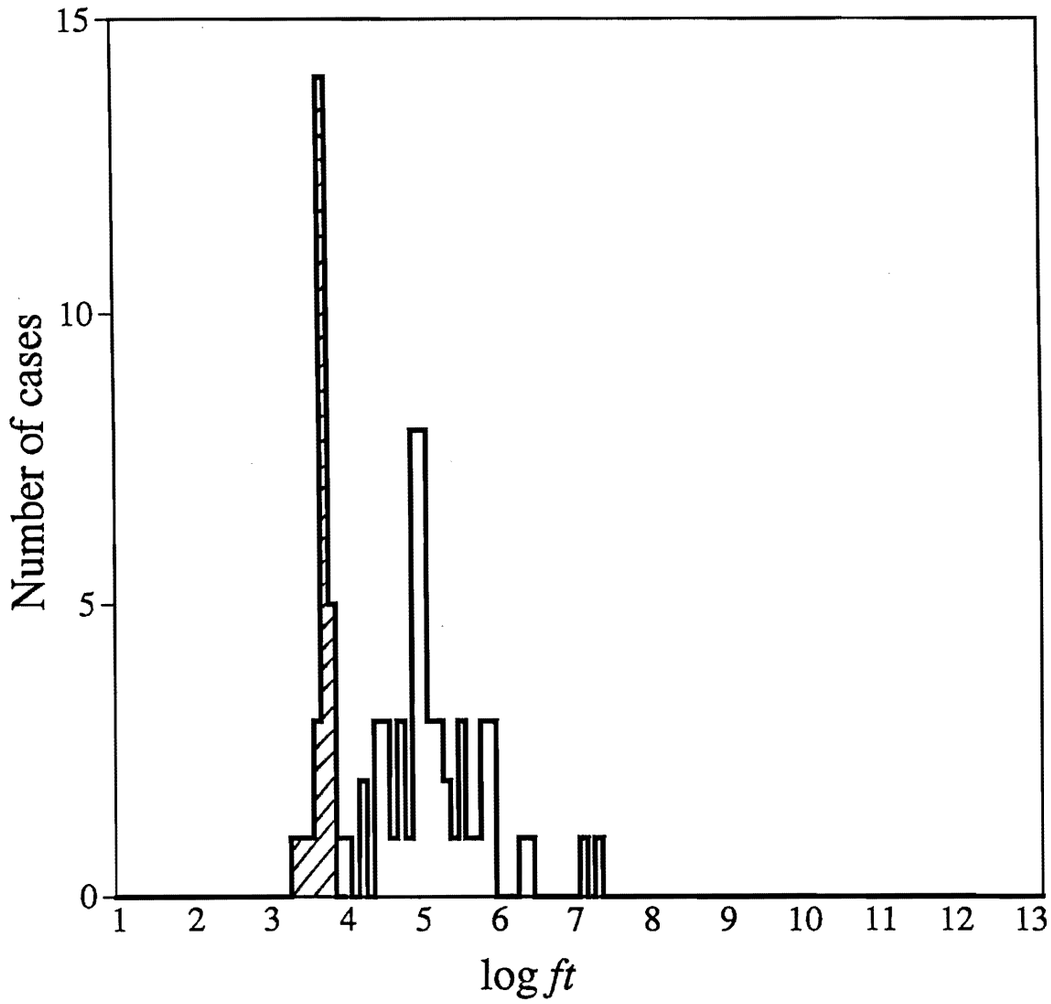

Fig. 5. Frequency distribution of log *ft* values for β transitions between miror nuclei ($10 < A \leq 100$). The hatched area (log $ft \leq 3.8$) corresponds to transitions between analogue states. The other events correspond to pure Gamow-Teller transitions as in Fig. 4a and 4b.

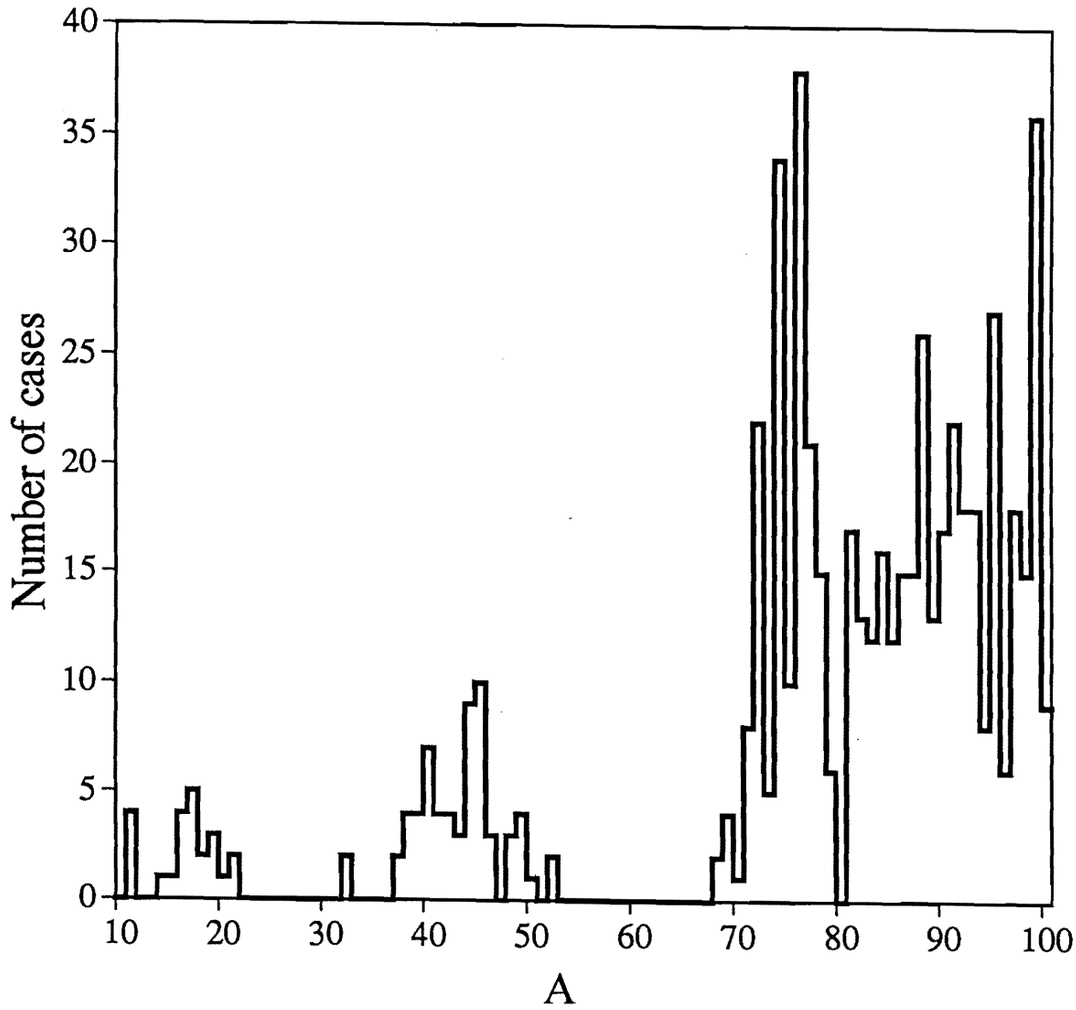

Fig. 6. Frequency distribution of $\log ft$ for first forbidden transitions ($\Delta J \leq 2$; parity change) according to the mass number ($10 < A \leq 100$). The clustering of these transitions near the A values corresponding to shell closures is apparent. The two cases reported for A = 32 are discussed in the text.

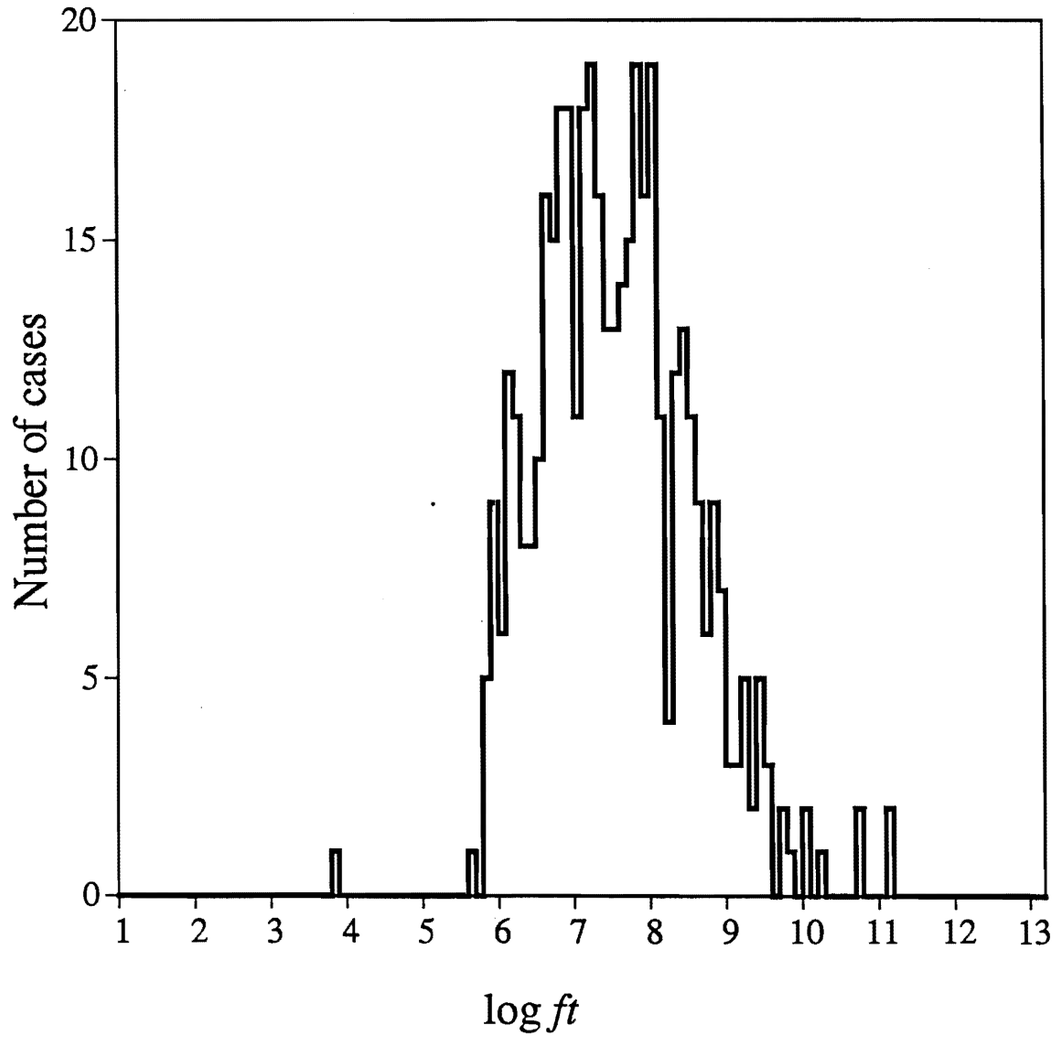

Fig. 7. Frequency distribution of log *ft* values for first forbidden non unique β transitions ($10 < A \leq 100$). The two cases with log *ft* < 5.7 belong to the particular class of transitions between 0^+ and 0^- states and are firmly established.

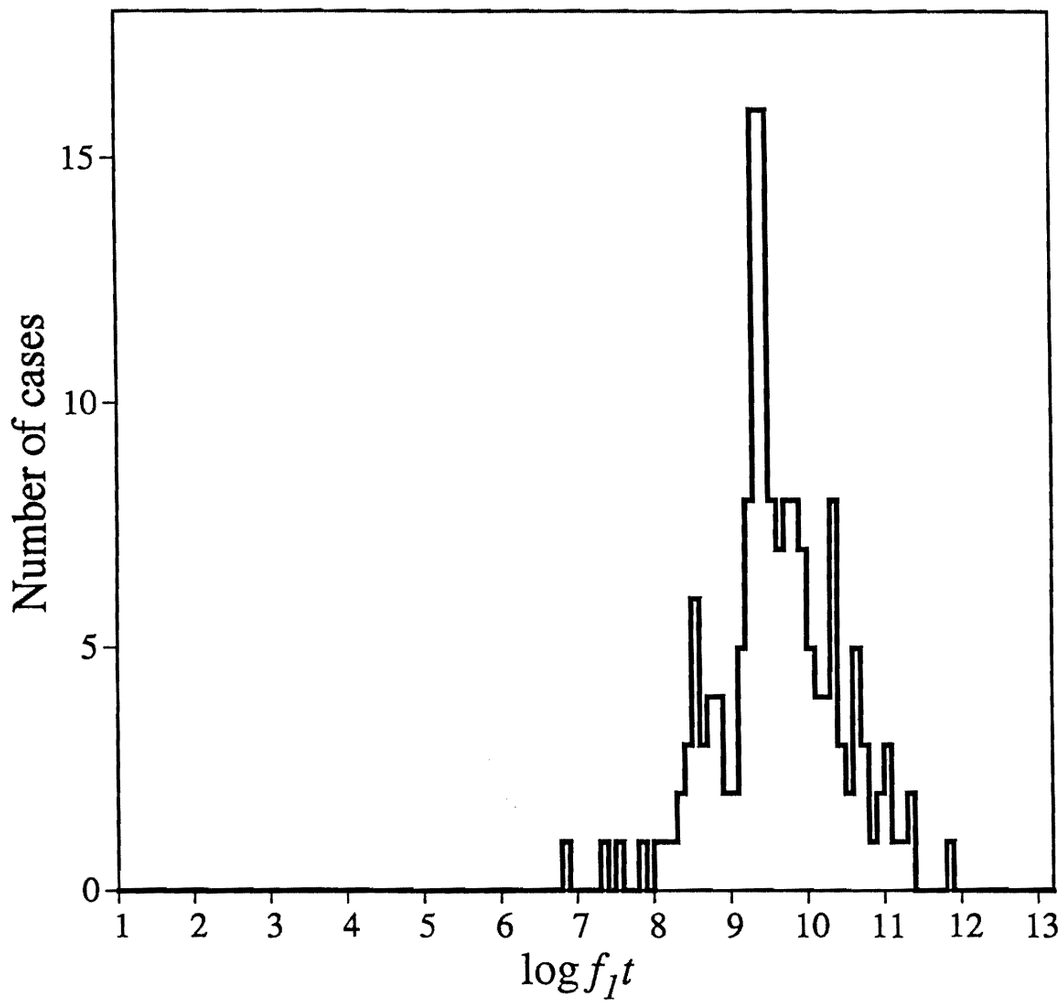

Fig. 8. Frequency distribution of $\log f_1 t$ values for first forbidden unique β transitions ($10 < A \leq 100$). The previous limit for this class of transitions was at $\log f_1 t = 8.5$. The four cases below $\log f_1 t = 8.0$ need further examination.

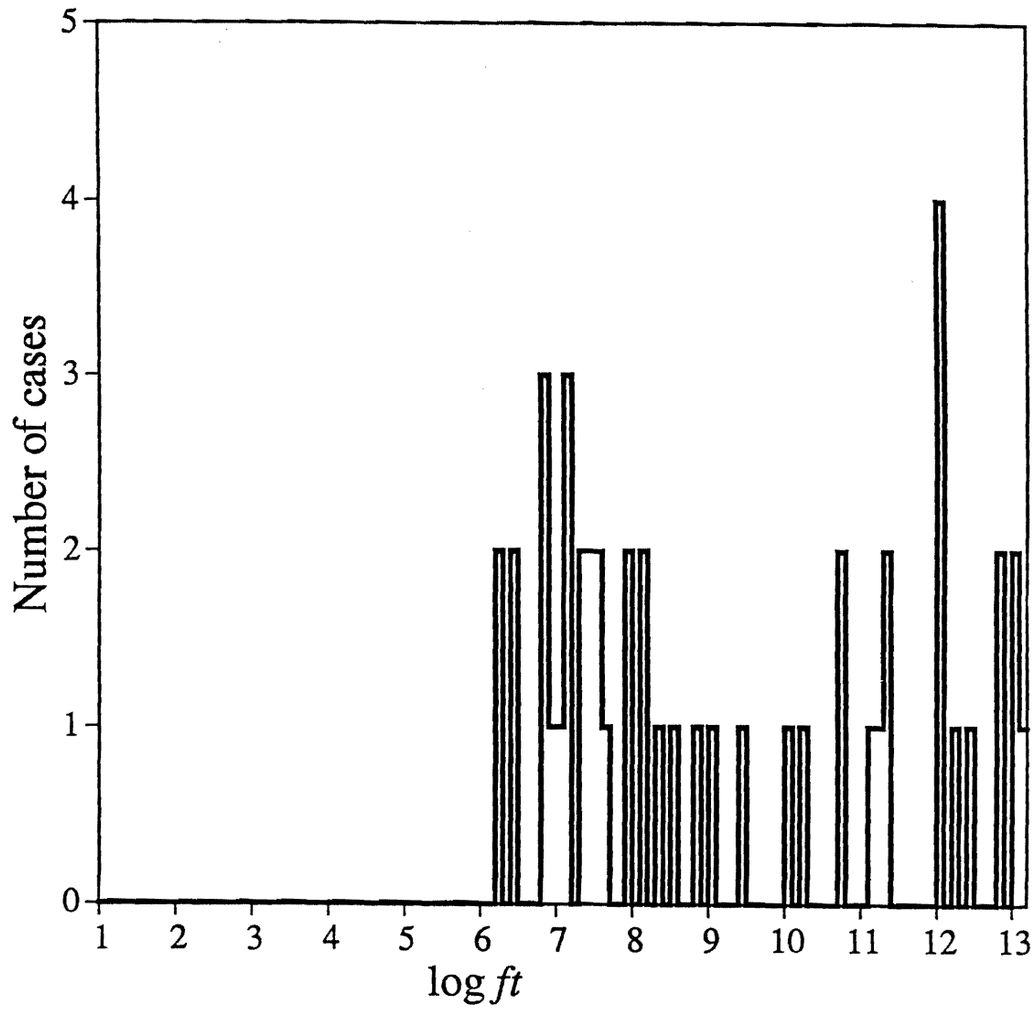

Fig. 9. Frequency distribution of log *ft* values for second forbidden non unique β transitions ($10 < A \leq 100$). This figure illustrates the fact that many such transitions are reported in the literature with log *ft* values lower than the limits given previously. Cases with log *ft* < 10.6 are discussed in the text and give no clear evidence of failure of the previous rules.