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MIRROR SYMMETRY IN THE β DECAY OF THE $A = 20$ AND 25 SYSTEMS*

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The half-life of F^{20} has been determined as 11.03 ± 0.06 sec and β branches have been measured in the decay of Na^{25}. By combining with information on Na^{20} and Si^{25} it is deduced that for the $A = 20$ mirror decays to the Ne^{20} 2^+ first-excited state, $(ft)^+/(ft)^- = 0.933 \pm 0.032$ or 1.062 ± 0.037, while in the $A = 25$ system $(ft)^+/(ft)^- = 1.187 \pm 0.076$ for β decay to all states below 3 MeV.

The simplest expectation for mirror β decays is that they should have identical ft values. It has, however, been known for some time that the ft value for N^{12} decay to the ground state of C^{12} is some 10% greater than that for the mirror decay of B^{12}. Careful analysis[1] suggests that the discrepancy may well be a significant one, not explicable in terms of electromagnetic, second-forbidden, isospin-mixing, and binding-energy corrections, and that its resolution may lie in the reality of second-class currents, specifically the induced tensor interaction,[2,3] i.e., that the β interaction does not respect G parity.[2] Before accepting this fundamental conclusion one must be sure both that the known corrections have been properly evaluated and that there are not others of a "structural" nature that may fluctuate from case to case.

It is therefore important to investigate other cases of mirror decay to see whether or not they fall systematically into line with $A = 12$. If the discrepancy in ft values was due solely to an induced tensor term its magnitude, for light nuclei and $W_0^{\pm} \gg 1$, should be proportional to $W_0^+ + W_0^-$ and approximately state independent.[3,4] We have carried out measurements on the systems $A = 20$ and 25 that enable us to extend the mirror test to these cases. We find that $A = 25$ shows a large departure from mirror symmetry in the same sense as for $A = 12$; the evidence on $A = 20$ is conflicting but suggests that the departure from mirror symmetry could have the opposite sense. These results emphasize the caution that must be used in interpreting the failure of mirror symmetry in terms of second-class currents.

The β^- decay of F^{20} is 99.92% to the first excited state of Ne^{20} at 1.63 MeV.[5] The β^+ decay of Na^{20} has been extensively investigated[6] by measurement of its β rays and the subsequent γ decay and α decay of Ne^{20}. The Na^{20} half-life is reported[6] as 408 ± 6 msec and the β branch to the first excited state of Ne^{20} as 90.0%. However, in view of technical problems in the β-ray measurements we have preferred to make our analysis in terms of the superallowed transition of Na^{20} to its analog in Ne^{20} at 10.270 ± 0.009 MeV.[7] For the Fermi part of this transition we have taken[8] $ft = 3060 \pm 20$ sec; for the Gamow-Teller part we have based ourselves on local systematics and taken the range $ft = 6.3 \times 10^4$-∞ sec; this leads to $ft = 2990 \pm 70$ sec for the two together. For the Na^{20} mass excess we have taken[6,9] 6.87 ± 0.04 MeV; we then use 7.35 ± 0.35 as the factor by which decay of Na^{20} to all α-unstable states of Ne^{20} exceeds its decay to its analog[6] to deduce a partial half-life of 2.03 ± 0.18 sec for decay to all α-unstable states. It is inferred[6] that Na^{20} decay to all γ-emitting states of Ne^{20} with the exception of the first excited state is negligible; decay to the first excited state is then deduced to have a partial half-life of 0.510 ± 0.015 sec and so for it $(ft)^+ = (8.77 \pm 0.29) \times 10^4$ sec. A more recent measurement[10] of the Na^{20} half-life gives 451.5 ± 9 msec. This disagrees strongly with the earlier[6] figure and corresponds to $(ft)^+ = (9.99 \pm 0.34) \times 10^4$ sec.

Comparison with F^{20} decay demands knowledge of the F^{20} half-life for which ostensibly accurate values in the literature range from[11] 10.31 ± 0.07 sec to[12] 11.56 ± 0.05 sec. We have accordingly measured this half-life. The F^{20} activity was made by bombarding BaF_2 with deuterons of 2.5 MeV and its decay was studied using both a plastic scintillator for the β rays (biased at about 1.5 MeV) and a NaI(Tl) crystal channeled on the 1.63-MeV line for the γ rays. Data were recorded in a time-channel analyzer driven by a quartz-crystal clock. Within the selected interval of 9 half-lives in the β-ray measurements and 6 half-lives in the γ-ray measurements there was no measurable departure of the net yield from a single pure exponential decay curve. From all measurements we deduce a F^{20} half-life of 11.03 ± 0.06 sec. Using standard masses we then find $(ft)^- = (9.403 \pm 0.065) \times 10^4$ and so, using the shorter[6] half-life for Na^{20}, $(ft)^+/(ft)^- = 0.933 \pm 0.032$ or, using the longer[10] half-life, $(ft)^+/(ft)^- = 1.062 \pm 0.037$. These results cannot meaningfully be averaged and the resolution of the problem awaits further measurement.

In the case of $A = 25$ we cannot compare β transitions to single states but only to groups of states. However, this is no great disadvantage at this stage if we are thinking in terms of testing for the induced tensor interaction since, as we have remarked, the effect of the latter is state independent to a first approximation. Decay of Si^{25} has been measured[13] to all proton-unstable states of Al^{25} down to and including that at 3.88 MeV. Between this state and that at 2.689 MeV no state is known of J^π suitable for receiving an allowed β transition from Si^{25}. We have investigated the β decay of Na^{25} to the analog, in Mg^{25}, of the 2.689-MeV state of Al^{25} and to all lower states. An estimate of the partial half-life of Si^{25} for all states down through that at 3.88 MeV then gives us, by subtraction from the total half-life, a figure for the partial half-life for decay to the 2.689-MeV state and all below it. This figure we may then compare with expectation derived from Na^{25} decay to the analogs in Mg^{25}.

We first discuss the analysis of Si^{25} decay. This we achieve, as for Na^{20}, by calibration via superallowed decay to the analog in Al^{25} at 7.916 ± 0.006 MeV.[14] In this case the Gamow-Teller component is taken from the Nilsson model assignments[15] which permit quite a large spread and that, together with the Fermi component, results in the estimate $ft = 1944 \pm 90$ sec. The mass excess of Si^{25} we take as 3.781 ± 0.050 MeV; the value comes from application of the isobaric-multiplet mass equation[16]; the error derives, conservatively, from the established success of this equation. We now use the fact[13] that the summed intensity of Si^{25} β decay to the 3.88-MeV and all higher states of Al^{25}, including the analog, exceeds decay to the analog by a factor of 3.22 ± 0.10; this leads to a partial half-life of 0.621 ± 0.052 sec for such decay and hence to a partial half-life of 0.336 ± 0.018 sec for decay to states below that at 3.88 MeV (using a total half-life of[13] 218 ± 4 msec).

The comparison with Na^{25} decay requires knowledge of the Na^{25} β branches. Although accurate ratios of β branches to the γ-emitting states have been obtained recently by Jones et al.,[17] the Na^{25} β branch to the ground state of Mg^{25} has apparently not been measured since the 1955 work of Maeder and Staehelin[18] who reported this branch as 65% with no error stated. In order to establish the decay scheme for Na^{25} (further details of which will be published later) we have made Na^{25} by bombarding targets of NaBr with tritons of 3.0 MeV and have studied its decay using a plastic scintillator for the β rays and NaI(Tl) and Ge(Li) counters for the γ rays. From the Ge(Li) spectra we derived the decay schemes of the Mg^{25} levels concerned and the relative β branches to excited states of Mg^{25}. From plastic-NaI coincidence measurements we derived the ground-state β branch in Na^{25} decay. Table I shows our results, combined, for the case of decay to excited states, with those deriving from the Ge(Li) investigation by Jones et al.,[7] which is concordant with ours. Table I also shows the ft values deduced for Na^{25} decay and, derived from them, the expectations for the decay constants of the analog branches in Si^{25} decay. (For the Na^{25} decay we use standard masses and a half-life of[19] 59.6 ± 0.7 sec.) Summing the expectations for Si^{25} decay gives a partial half-life of 0.283 ± 0.010 sec and so $(ft)^+/(ft)^- = 1.187 \pm 0.076$.

Table I. Decay of Na^{25} to states of Mg^{25} and computed decay constants for Si^{25} decay to the analogs in Al^{25}.

Mg^{25} state	Branch (%)	$10^{-5}ft$	Al^{25} state	λ (sec^{-1})
2.801	0.28 ± 0.05	1.6 ± 0.3	2.689	0.244
1.965	0.50 ± 0.08	9.9 ± 1.6	1.810	0.061
1.612	9.5 ± 0.6	1.09 ± 0.07	1.610	0.607
0.975	27.2 ± 1.4	1.13 ± 0.06	0.949	0.792
0	62.5 ± 2.0	1.81 ± 0.07	0	0.741

The $W_0^+ + W_0^-$ values are similar for the cases investigated here (35 and 30 for $A = 20$ and 25, respectively). A linear extrapolation in $W_0^+ + W_0^-$ from the ft-value discrepancy at $A = 12$ would give $(ft)^+/(ft)^- = 1.06$ as the expectation at $W_0^+ + W_0^- = 30$. A survey[20] comprising 11 A values in all reveals a predominance of positive values for $(ft)^+/(ft)^- - 1$ and gives an expectation of about 1.08 for $(ft)^+/(ft)^-$ at $W_0^+ + W_0^- = 30$.

It is clear that large departures from charge symmetry in β decay cannot be due to electromagnetic, second-forbidden, or isospin-mixing effects[1] and, furthermore, that allowance for such effects tends to increase the raw $(ft)^+/(ft)^-$ ratios even further. The only "trivial" effect that is of the right sign and possibly of the right magnitude to resolve the discrepancy is the differential effect on the overlap integrals of the differing binding energies in the two sides of the decay system. The most realistic of the older estimates[1,21] of this effect for $A = 12$ gave an upper limit of 5%; very recent estimates[22] using relativistic nuclear wave functions and a range of binding energies suggest a significantly lower figure even for rather extreme binding-energy changes. It appears at the moment that simple structure effects are not likely to be responsible; the possibility that differences of deformation[21] might be significant has not been adequately explored but is perhaps unlikely in view of the extreme constancy of the ft values of superallowed Fermi transitions. The remaining radical explanation, the reality of the induced tensor interaction, is very far from established but must be seriously entertained.

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