The $^{35}Ar(\beta^+)^{35}Cl$ Decay and the Anomalous Cabbibo Angle

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Abstract

The threshold energy for the $^{35}Cl(p,n)^{35}Ar$ reaction has been measured to be $6943 \cdot 0 \pm 1 \cdot 0$ keV, the corresponding endpoint energy for the $^{35}Ar(\beta^+)^{35}Cl$ mirror decay being $4943 \cdot 4 \pm 1 \cdot 0$ keV. This confirms the value $4941 \cdot 6 \pm 1 \cdot 7$ keV found by Freeman *et al.* (1969) and invalidates a possible explanation of the anomalous behaviour of the ^{35}Ar decay.

Careful studies of pure Fermi super-allowed nuclear β decays have yielded very consistent and accurate values for the vector coupling constant G_v (Hardy and Towner 1975*a*; Raman *et al.* 1975; Wilkinson and Alburger 1976). It has further been shown by Hardy and Towner (1975*b*) that this consistency is maintained in the values of G_v extracted from the mixed vector, axial-vector decays of the neutron and ^{19}Ne. By contrast, analyses of the decay of ^{35}Ar to the ^{35}Cl ground state (Wick *et al.* 1969; Hardy and Towner 1975*b*) have yielded significantly higher values of G_v, and a Cabbibo angle consistent with zero rather than the normal value of $\arcsin 0 \cdot 232$ (Roos 1974). This has led to speculation regarding mechanisms that could cause the Cabbibo angle to 'vanish' in a nuclear decay (Hardy and Towner 1975*b*).

The calculation of G_v for such decays requires a knowledge of the *ft* value for the transition, and the ratio of its axial-vector to vector terms (Wick *et al.* 1969). This ratio can be obtained from measurements of the asymmetry A in the positron angular distribution from polarized nuclei. Currently available asymmetry measurements for ^{35}Ar yield values of A equal to $0 \cdot 16 \pm 0 \cdot 04$ (Calaprice *et al.* 1965), $0 \cdot 213 \pm 0 \cdot 04$ (Calaprice 1967), $0 \cdot 23 \pm 0 \cdot 05$ and $0 \cdot 33 \pm 0 \cdot 06$ (Mead 1974). The ^{35}Ar analyses referred to above used either the earlier results (Wick *et al.* 1969) or a weighted mean of all four results (Hardy and Towner 1975*b*) together with a combination of the most accurate measurements of the positron endpoint energy by Freeman *et al.* (1969) and the ^{35}Ar decay branching ratio and half-life.

A solution to this ^{35}Ar problem has now been proposed by Szybisz and Rao (1976) who showed that by choosing the highest of the above asymmetry values, and an earlier and less accurate result for the endpoint energy obtained by Cramer and Mangelson (1968), which is $26 \cdot 9$ keV higher than the value of Freeman *et al.* (1969) used in the analyses discussed above, the anomalies in the value of G_v and the Cabbibo angle disappear. Their choice for A may be reasonable, but their selection of the endpoint energy is very dubious. Both this earlier value, $4968 \cdot 5 \pm 3 \cdot 5$ keV of Cramer and Mangelson, and the more recent result, $4941 \cdot 6 \pm 1 \cdot 7$ keV of Freeman *et al.*, were deduced from measurements of the $^{35}Cl(p,n)^{35}Ar$ threshold energy, and

Freeman *et al.* showed that resonances in the (p, n) cross section provide a very reasonable basis for the incorrectness of the higher value.

To resolve this discrepancy we have made a further measurement of the ^{35}Cl(p, n)^{35}Ar threshold energy. Targets made by evaporating analar KCl onto tantalum backings were bombarded for 4 s (about two half-lives). The beam was then interrupted and the target transported 40 cm to a shielded plastic scintillator which recorded the resulting positron activity for 4 s in pulse-height mode and for 10·24 s in a 256-channel multiscaler. This cycle was repeated 40 times at 2–3 keV intervals over a region of about 30 keV spanning the threshold. Yield curves were extracted for different regions of the pulse-height data, and from the multiscaler array by comparing the yield in groups of early and late channels. The proton energy scale of the accelerator was calibrated during each threshold run in terms of the accurately known energies of the 6·05–6·09 MeV ^{212}Bi α-particle doublet (Rytz 1973) using a magnetic spectrograph. The technique employed is described in detail elsewhere (Barker *et al.* 1977).

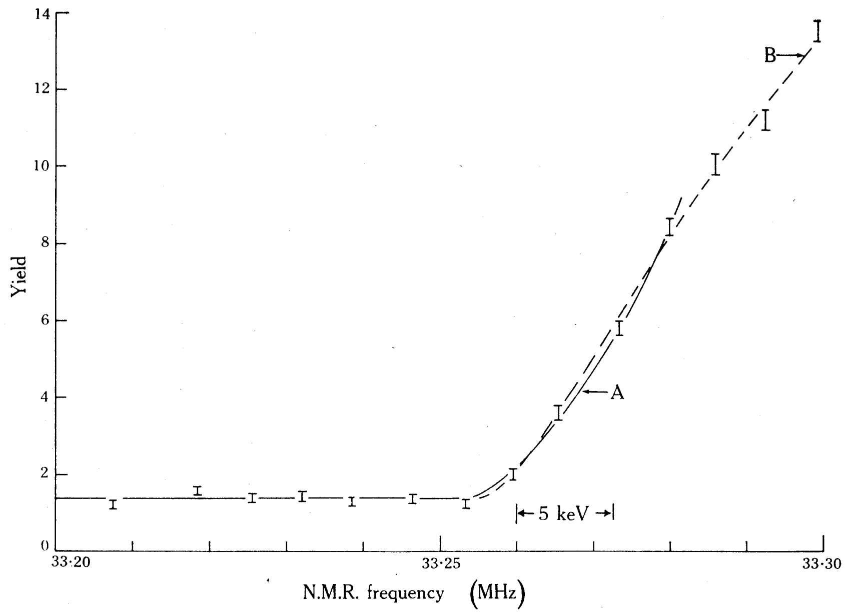

Fig. 1. Yield curve for the ^{35}Cl(p, n)^{35}Ar reaction. Fit A (solid curve) is for pure s-wave neutron emission, with a target about 10 keV thick, and gives a value for the threshold energy E_{th} of 6942·4±0·5 keV. Fit B (dashed curve) is for s-wave neutron emission with a weak resonance in the cross section near threshold; this gives the result E_{th} = 6943·5±0·5 keV. The errors quoted are from the fits only.

Five threshold runs were used for analysis; a typical yield curve in pulse-height mode is shown in Fig. 1. Small departures from a pure s-wave neutron yield were found for energies greater than about 10 keV above threshold in both the pulse-height and multiscaler data, which implies an effect associated with the ^{35}Cl(p, n) reaction, since known impurities in the target do not yield half-lives similar to that of ^{35}Ar. This could be due to the targets used only being about 10 keV thick. Data in this 10 keV interval could be consistently fitted with a function of the form

$$Y = a + b(f - f\,)^{3/2}$$

where f is the n.m.r. frequency of the 90° analysing magnet and f_0 the threshold frequency. The solid curve in Fig. 1 shows such a fit. The mean threshold energy from this analysis is $6942\cdot4 \pm 0\cdot5$ keV. However, three different evaporated targets were used and the structure in the yield curve although weak was reasonably reproduced in all runs.

The full energy range covered could be fitted consistently using a form approximating a weak resonance in the yield near threshold (Naylor and White 1977, forthcoming). A fit made on this basis is shown by the dashed curve in Fig. 1. This analysis yields a mean threshold energy of $6943\cdot0 \pm 0\cdot5$ keV. Since efforts were made to ensure that the later targets were thick for these measurements we feel that target thickness is unlikely to be the source of the observed structure and have adopted the value $6943\cdot0$ keV for the threshold energy, but with the error increased to $\pm 1\cdot0$ keV to allow for these uncertainties. This final value includes corrections for beam-energy spread and discrete energy-loss effects, and for small errors due to hysteresis and other effects in the energy calibration procedure.

The present result is quite consistent with the value of $6941\cdot2 \pm 1\cdot7$ keV found by Freeman *et al.* (1969) for the threshold energy, and is further supported by the value 6943 ± 4 keV given by Noda *et al.* (1970), who also measured this threshold energy, although their result is not referred to by Szybisz and Rao (1976). The weighted mean threshold energy from these results is $6942\cdot6 \pm 0\cdot8$ keV and would now seem to be sufficiently well-established to exclude the value of $6968\cdot9 \pm 3\cdot5$ keV given by Cramer and Mangelson (1968). The corresponding mean Q value is $6747\cdot5 \pm 0\cdot8$ keV, and the endpoint energy is $4943\cdot0 \pm 0\cdot8$ keV.

The conclusion reached by Szybisz and Rao (1976), that the ^{35}Ar anomaly can be explained using existing data, appears to be invalid. However, as their calculations show, the amounts by which the values of G_v and the Cabbibo angle deduced from the data are anomalous depend in particular on the value used for the asymmetry parameter, and a clarification of this point will be necessary before the significance of the ^{35}Ar anomaly becomes clear.

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Manuscript received 1 February 1977