Measurement of the Alignment–Positron-Momentum Correlation in $^{12}N \to {}^{12}C$(g.s.) by the Spontaneous-Level-Mixing Technique: Improved Evidence against a Second-Class Axial Current

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The coefficient α_+ of the alignment–positron-momentum correlation in the decay $^{12}N \to {}^{12}C$(g.s.) has been determined using the technique of spontaneous level mixing. We find $\alpha_+ = -2.73(39)$/GeV; this agrees with the revised result of Sugimoto *et al.* The two coefficients $\alpha_\pm$ jointly yield [assuming strong conservation of vector current (CVC)] $F_E^{(2)}/F_A = -0.13(48)/2M$, i.e., provide strong evidence against a second-class axial current in a model-independent way. Conversely, assuming $F_E^{(2)} \equiv 0$ yields $F_M/F_A = 3.93(48)/2M$, in excellent agreement with the CVC prediction.

It is by now well accepted that the most compelling evidence concerning the possible presence of second-class currents in nuclear β decay can be obtained from angular correlation experiments with oriented mirror nuclei. Specifically, for a $1^+ \to 0^+$ $\beta^\pm$ decay [e.g., $^{12}B \to {}^{12}C(g.s) \leftarrow {}^{12}N$], one has the relation[1]

$$W(\theta, E)_\pm = F_\pm(E)[1 \pm P(1+\alpha_\pm E)P_1(\theta) + A\alpha_\pm E P_2(\theta)], \qquad (1)$$

where P (A) is the polarization (alignment) of the parent nucleus, E is the electron kinetic energy, and $P_l(\theta)$ are Legendre polynomials. The terms $\alpha_\mp E$ are contributed by *gradient* couplings (weak electricity and weak magnetism) and recoil terms. In the "elementary particle" treatment[1] one has

$$\alpha_\pm = (\tfrac{2}{3}F_A)[\mp(F_M - F_E^{(2)}) - F_E^{(1)}], \qquad (2)$$

where the F_i's are form factors (A denotes axial vector). Note that $F_E^{(k)}$ has potentially both first- ($k=1$) and second-class ($k=2$) parts. It is the presence or absence of $F_E^{(2)}$ which is the crucial question at stake. It is obvious that one-branch determinations (α_+ *or* α_-) can provide information on $F_E^{(2)}$ only if assumptions about *both* F_M and $F_E^{(1)}$ are made. The value of F_M follows from the hypothesis of strong conservation of vector-current (CVC) (reasonably corroborated by recent[2,3] and revised[4] experiments), while $F_E^{(1)}$ may be computed in the impulse approximation, where $F_E^{(1)}/F_A = (\tfrac{1}{2}M)[1 + 2i\int \vec{r}(\vec{\sigma}\cdot\vec{p})/\int\vec{\sigma}] \equiv y/2M$. On the other hand, two-branch determinations yield $F_E^{(2)}$ from

$$F_E^{(2)}/F_A = F_M/F_A - \tfrac{3}{4}(\alpha_- - \alpha_+), \qquad (3)$$

without requiring any knowledge of $F_E^{(1)}$, which perhaps could be model dependent.[5,6]

From any reasonable estimate, the coefficients $\alpha_\pm$ are anticipated to be very small, of the order of a few percent per MeV. Their reliable determination via the polarization term in (1), where they contribute but a small correction, is hence extremely difficult. A direct measurement of the *alignment* term in (1) is evidently more appropriate. Lebrun *et al.*[7] have devised a method for such measurements, based on the alignment A *induced* by NMR techniques from a given initial polarization P_0 in such a way that the sign of A could be reversed at will. Their result,[7] $\alpha_-(E_0) = -(0.07 \pm 0.20)$/GeV, contradicted the earlier results[8] based on the delicate polarization correlation and was in good agreement with the prediction, $\alpha_- = 0.04$/GeV, corresponding to $F_E^{(2)} = 0$, i.e., the absence of a second-class axial current. This result was then confirmed by Brändle *et al.*,[9] who produced the reversible induced alignment by a slightly different technique which did not make use of rf transitions, but rather exploited the phenomenon of "spontaneous level mixing." Finally, Sugimoto *et al.* adopted the induced-alignment approach[10] and redetermined *both* α_- and α_+; their result for α_- confirms that of Refs. 7 and 9, while their α_+ agrees essentially with their earlier value[8] obtained via the polarization term.

In view of this experimental situation and of the discussion following Eq. (2), we consider it useful to present an independent determination of α_+, performed by means of a slight variation of the method described in Ref. 9.

^{12}N was produced by the reaction $^{10}B(^3He, n)^{12}N$, operating at $E_{He} = 4.0$ MeV and at a recoil angle of

$25° \pm 4°$. Because of the small yield of this reaction a very intense beam (50–80 μA) was needed, and the "straight-through" bombardment of a thin target (as in Ref. 9) was not practical. A thick ($\sim 250\ \mu g/cm^2$) ^{10}B layer, evaporated onto the perimeter of a rotary target[11] (see Fig. 1), was used.[12] The recoil "catcher," the Helmholtz coils, and the two detector telescopes were essentially the same[13] as in Ref. 9. The perimeter structure of the target was such that it intercepted the ^{3}He beam during $\frac{1}{3}$ of each revolution, letting it through for the rest. At 11 rps, this corresponds to a bombardment/observation sequence of (17 msec)/(28 msec). A photodiode "viewing" the rim of the target provided reference pulses for gating the telescope outputs. Monitoring was twofold: (a) with a Faraday cup collecting the unintercepted beam; (b) by observing the equilibrium ^{12}N activity with a special telescope. The voltage on the photomultipliers (EMI 9823) of the large scintillators used for energy analysis was lowered by 150 V during each bombardment interval to prevent "fatigue" effects, and the gain of their amplifier chain was kept constant by means of light diodes and a commercial stabilization system.[14] The "lines" produced by these diodes were recorded together with the β spectra. Data with different field settings (up/down, on/off the crossing point B^*, etc.) were collected with rapid cycling (intervals of 17 sec) and appropriately stored.

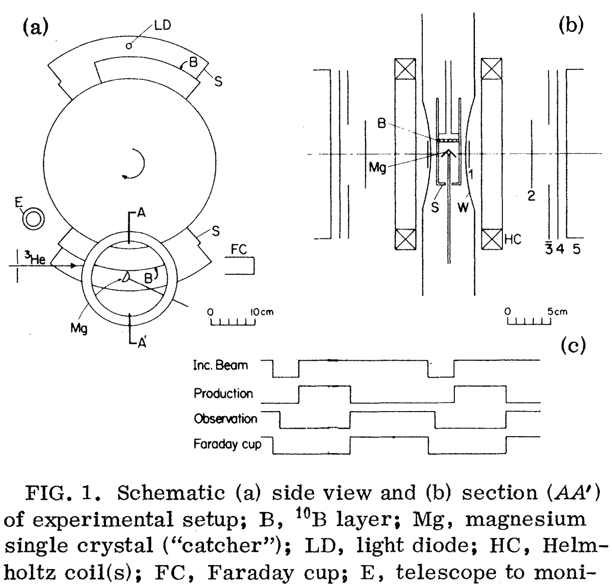

FIG. 1. Schematic (a) side view and (b) section (AA') of experimental setup; B, ^{10}B layer; Mg, magnesium single crystal ("catcher"); LD, light diode; HC, Helmholtz coil(s); FC, Faraday cup; E, telescope to monitor activity; W, Mylar window; S, shield. (c) Time-sequence program.

Figure 2, analogous to Fig. 2 of Ref. 9, shows the observed asymmetries near B^*. These data, corrected for possible imperfections of the monitoring by means of data with a Teflon (depolarizing) target, yield the *effective* orientations $P^0 = (17.7 \pm 0.7)\%$ and $A^0 = (3.6 \pm 0.7)\%$.

Thanks to special care with the shielding, field-induced gain shifts were absent in all the counters. Small direct effects on the counting rates, due to slight changes in the beam position, were however observed. The analysis was therefore performed as follows: From the corrected rates $N_{\uparrow(\downarrow)}(\theta, E)$ we formed the signal[9]

$$S(\theta,E) = \frac{2[N_\downarrow(\theta,E) - N_\uparrow(\theta,E)]}{N_\downarrow(\theta,E) + N_\uparrow(\theta,E)} = \frac{\frac{3}{2}P^0\alpha_+ EP_2(\theta) + \frac{1}{2}A^0P_1(\theta)}{1 + \frac{3}{4}P^0P_1(\theta)}. \quad (4)$$

The corrections for field-dependent effects were determined from the average of concurrently recorded off-resonance data (at $B^* \pm 35$ G), and separate data from a depolarizing catcher (the actual implantation target covered with a Teflon film). Polarization and alignment were constantly monitored via the rapid-cycling technique. Combination of the signals S from the two telescopes, i.e., $\theta = 0$ and π, readily yields $|\alpha_+|$ and $|A^0|$.

Figure 3 shows the observed asymmetry ($\sim \alpha_+ E$) vs E, as well as a typical spectrum with the energy bins used for the analysis. The fit yields

$$\alpha_+ = -2.73(39)/\text{GeV}, \quad (5)$$

where the uncertainty includes besides the statis-

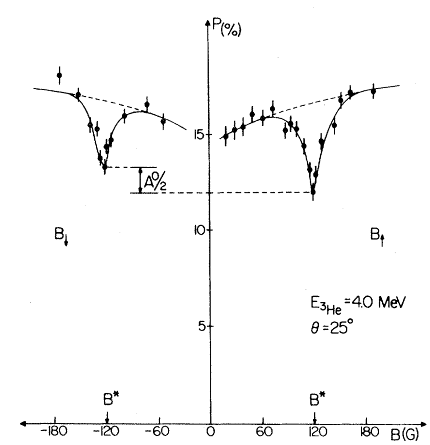

FIG. 2. Polarization of ^{12}N recoils from ^{10}B(^{3}He,n) implanted into a Mg single crystal, with c axis parallel to B field.

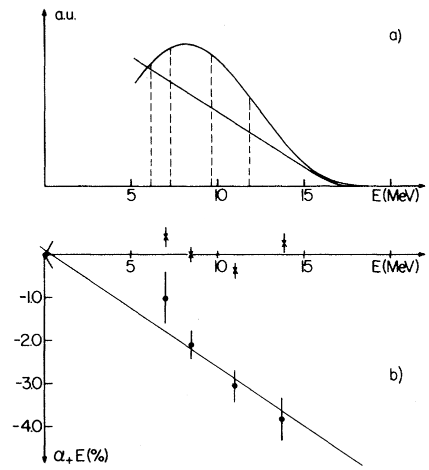

FIG. 3. Typical β^+ spectrum (a) with its Kurie plot and the observed asymmetry (b) as a function of β^+ energy. Corrections were applied for spurious asymmetries determined by off-resonance data (crosses). The point at $E = 0$ is their average value; its error bar includes an allowance for systematic uncertainties.

tical error (± 10%) an allowance for systematics [energy scale (3%), finite angular apertures (2%), polarization (5%), and normalization (8%)]. The sign of α_+ is not directly derivable from an experiment of our type, since that of the alignment of ^{12}N produced under our kinematical conditions is not known. In (5), we assumed the sign of α_+ as preferred by an argument comparing $(ft)_+$ and $(ft)_-$.[15] This result agrees with that predicted[1] for the "orthodox" interaction, i.e., $F_E^{(2)} = 0$, as well as with the results of both Refs. 8 and 10.

Table I summarizes all currently available data from alignment experiments. Using the weighted means, and Eq. (3) with the CVC value $F_M/F_A = 3.8/2M$, one obtains

$$F_E^{(2)}/F_A = -0.13(48)/2M, \qquad (6)$$

i.e., good evidence against the presence of a second-class (induced-tensor) coupling. Conversely, $F_E^{(2)} \equiv 0$ yields $F_M/F_A = 3.93(48)/2M$, in perfect accord with the CVC value. On the other hand, $\alpha_+ + \alpha_-$ yields

$$F_E^{(1)}/F_A \equiv y/2M = 3.79(48)/2M, \qquad (7)$$

in excellent agreement with the "orthodox" impulse-approximation prediction.[16] There thus appears to be little room for the exchange-current contribution estimated by Kubodera *et al.*[6]

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TABLE I. Summary of observed alignment coefficients. Experiments on same line used identical techniques.

	α_- (GeV^{-1})	α_+ (GeV^{-1})
	0.1 ± 0.3 [a]	-2.73 ± 0.39 [b]
	-0.07 ± 0.20 [c]	...
	$+0.24 \pm 0.44$ [d]	...
	$+0.25 \pm 0.35$ [e]	-2.77 ± 0.52 [e]
Weighted mean	0.05 ± 0.14	-2.74 ± 0.31

[a] Present authors, preliminary result.
[b] Present result.
[c] Ref. 7.
[d] Ref. 9.
[e] Ref. 10.

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[11]This well-known device [cf., e.g., E. Rutherford *et al.*, *Radiations from Radioactive Substances* (Cambridge Univ. Press, Cambridge, 1930)] was also used in Ref. 10.

[12]We used the same device in a repetition of the α_- measurement (to be published).

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Observation of New Satellites in the Cs-Ar System Using Resonance Ionization Spectroscopy

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The absorption line shape of Cs-Ar system is recorded using two-photon ionization of the system with Cs(7*P*) as an intermediate state. New satellite structures in the wings of Cs(7*P*) are observed which were not resolved in previous absorption measurements. Also the absolute absorption cross section in the blue wing is measured.

Recently, we suggested[1] and reported[2] on a two-photon ionization method for collisional line broadening. The resonance ionization spectroscopy scheme (RIS) results in the conversion of all absorption events to ion pairs in a two-photon ionization process. Conversion of absorption events to ion pairs increases the sensitivity of the detection since it is easier to detect a small number of electrons than a small number of photons in absorption or fluorescence. The increased sensitivity achieved in the ionization method, over the traditional absorption[3] and fluorescence methods,[4] allows measurements at the far wing of optically thin samples and with low pressure of buffer gases where self-broadening, dimer absorption, and three-body collisions are essentially eliminated. The present Letter reports on the demonstration of such sensitivity and the potential of this method. We have resolved satellite structure in the wings of Cs(7*P*) broadened by Ar which was not observed in the absorption measurements previously taken.[3] A recent calculation predicts the presence of the structure[5]; however, the positions do not agree completely with this experiment. Also the absolute absorption cross section in the blue wing is measured. The extra sensitivity achieved in this method also allowed the detection and identification of single atoms of Cs in the presence of other species.[6]

Collisional line broadening is traditionally studied by absorption[3] or fluorescence.[4] Recently a variation of the traditional fluorescence method was developed.[7] The system is excited in the wing, and the collisional redistribution of scattered light is studied as a function of the detuning of the incident light. Optical collision cross sections are then derived.

In the present measurements, a mixture of Cs and Ar at room temperature is photoionized by absorption of two photons from a 1-μsec pulse from a dye laser tuned to 455 nm. The collisionally broadened Cs(7*P*) states serve as an intermediate state of the process. Low Cs density ($10^9/\text{cm}^3$) is used which is seven orders of magnitude less than what was used in the previous absorption studies. The details of the experimental setup were given in Ref. 6. The laser wavelength was tuned in 1–2-Å increments across both the $7P_{3/2}$ and $7P_{1/2}$ fine structure levels. At each setting, the dependence of the two-photon ionization yield on the pulse energy was recorded. The pulse magnitude ranged over two orders of magnitude (5×10^{16}–5×10^{18} photons/cm^2). At each pulse energy the two-photon ionization line shape can be easily plotted.

Figure 1 shows the combined line shape of both

