Beta-Decay Asymmetry and Nuclear Magnetic Moment of Argon-35†

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The asymmetry in beta emission from polarized Ar^{35} nuclei and the nuclear magnetic moment of Ar^{35} have been determined by an atomic-beam method used previously for similar measurements on Ne^{19}. The results are: for the asymmetry parameter, $A=+0.16\pm0.04$; and for the nuclear moment, $\mu=+0.632\pm0.002$ nm. The experimental value of A is used to obtain the Gamow-Teller beta-decay matrix element: $\langle\sigma\rangle=0.10\pm0.05$. This result is consistent with the measured ft value and electron-neutrino angular correlation coefficient in the decay of Ar^{35}. The results are also consistent with a rotational model of Ar^{35} using a deformation parameter close to that of Cl^{35}.

IN allowed beta decay, the angular distribution of electrons emitted from polarized nuclei is given by[1]

$$W(\theta)=1+(\langle m_I\rangle/I)A(v/c)\cos\theta\,, \tag{1}$$

where I is the spin of the parent nucleus, v is the electron velocity, c is the velocity of light, and θ is the angle between the direction of electron emission and the spin quantization axis. We have measured the beta-decay asymmetry parameter A for argon-35 and have determined the nuclear magnetic moment of argon-35 by observing the change in $W(\theta)$ which occurs when nuclear polarization is altered by resonance reorientation. The results are as follows:

$$A(Ar^{35})=+0.16\pm0.04 \tag{2}$$

and

$$\mu(Ar^{35})=+0.632\pm0.002\text{ nm}. \tag{3}$$

The experimental method, used previously for a similar experiment on neon-19,[2,3] is outlined below. Argon-35 atoms produced in the reaction $Cl^{35}(p,n)Ar^{35}$ emerge from an atomic beam source (see Fig. 1) and traverse an inhomogeneous magnetic deflecting field of the conventional type.[4] The atomic beam defined by the source slit and a movable collimator slit located in the center of the deflecting magnet is split into four spatially displaced partial beams corresponding to the possible values of m_I ($I=\frac{3}{2}$). The beam emerges from the deflecting field, passes through a homogeneous magnetic field where rf transitions may be induced, and enters a detector bulb through a long narrow channel. The number of atoms in each partial beam entering the bulb has been calculated as a function of the collimator position (see Fig. 2). The polarization of atoms entering the bulb reverses when the collimator is moved from one side of the beam center axis to the other.

Most of the argon 35 atoms which enter the bulb decay there, since their half-life[5] (1.8 sec) is short compared to the mean time for escape from the bulb (10 sec). Positrons emitted in the directions of the thin end-walls of the bulb penetrate them with little energy loss and are detected with Geiger counters. Relaxation of nuclear spin polarization is found to be negligible and positron emission is asymmetric.

We obtained counts N_1 and N_2 from counters 1 and 2 during 3-min time intervals, at collimator positions of ±0.013 cm. Although neither of the quantities

$$R_{\pm}=(N_1-N_2/N_1+N_2)\,, \tag{4}$$

with background correction included, can be used separately to determine the asymmetry parameter A because of differences in counter efficiencies and bulb end-wall thicknesses, the quantity $\Delta=R_+-R_-$ is directly related to A. The quantity A can be determined by averaging Eq. (1) over the acceptance solid angles of the counters, the uniform distribution of decaying atoms in the volume of the bulb, and the positron velocity distribution (with a low velocity cutoff to account for window transmission effects). A correction must also be made for the effect of positron backscattering in the thick cylindrical wall of the bulb.[6,7] Backscattered positrons contribute equally to N_1 and N_2 and thereby reduce Δ by $(15\pm5)\%$.

Two errors were made in the evaluation of A for neon-19.[2] The backscattering correction was neglected, and a factor of 2 relating A to Δ was omitted. The corrected

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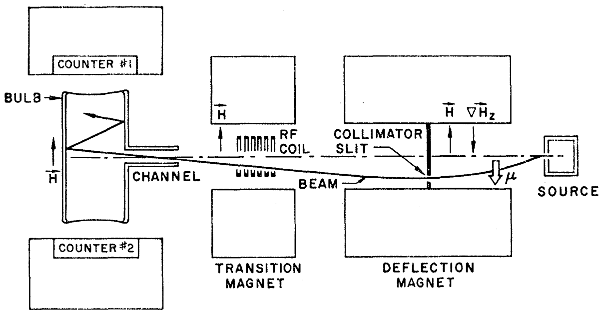

FIG. 1. Schematic drawing of apparatus (not to scale). The orbit of an argon-35 atom with $m_I=-\frac{3}{2}$ is shown. The collimator setting is negative.

value is

$$A(\mathrm{Ne}^{19})=-0.033\pm0.002. \qquad (5)$$

We measured the nuclear moment of argon-35 by observing the change in Δ accompanying rf transitions between m_I states, and employed a rotating rf magnetic field to determine the sign of the moment.[8] The signs of μ and Δ determine the sign of A. After the initial resonance search, we obtained a large amount of data at three frequencies (see Table I). The resonance curve center could be determined directly from this data, since the curve should be symmetric. The diamagnetic correction to the moment is small compared to the uncertainty.

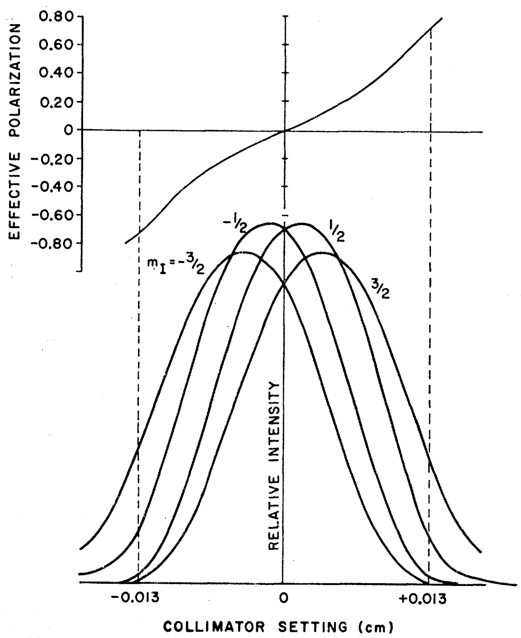

FIG. 2. Relative intensity of the four partial beams and effective polarization of atoms entering the bulb as a function of collimator setting.

[8] See Ref. 4, p. 145.

TABLE I. Change in Δ at nuclear resonance.

Frequency (kc/sec)	Δ
369.5	-0.002 ± 0.01
371.5	-0.040 ± 0.01
373.5	-0.002 ± 0.01
rf off	$+0.140\pm0.02$

The decay scheme of Ar^{35} is shown in Fig. 3.[9] The measured asymmetry can be expressed in terms of the asymmetries of the three decay modes according to the expression

$$A=0.93A_0+0.05A_1+0.02A_2, \qquad (6)$$

where A_0, A_1, and A_2 are the asymmetries associated with each decay mode, and the numerical coefficients are the respective branching ratios. The spin of Cl^{35} is known only for the ground state so that A_1 and A_2 are uncertain. Since $I=\frac{3}{2}$ for Ar^{35} we obtain

$$A_0(\mathrm{Ar}^{35})=\frac{\frac{2}{5}|C_A|^2|\langle\sigma\rangle|^2+2(\frac{3}{5})^{1/2}|C_A|\,|C_V|\langle 1\rangle\langle\sigma\rangle}{|C_V|^2|\langle 1\rangle|^2+|C_A|^2|\langle\sigma\rangle|^2}, \qquad (7)$$

where C_V and C_A are the Fermi and Gamow-Teller coupling constants, respectively (assumed to be real

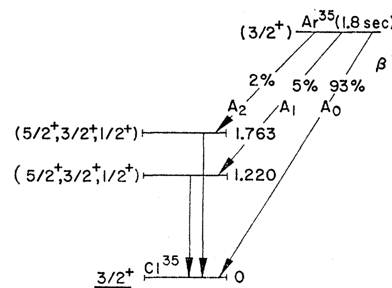

FIG. 3. Decay scheme of argon-35.

and of opposite sign).[10] The Fermi matrix element is unity to a good approximation. We choose for the coupling constant ratio the value which gives the best agreement for the ft values[11] of O^{14}, O^{15}, F^{17}, and Sc^{41}:

$$(C_A/C_V)^2=1.16\pm0.05. \qquad (8)$$

Substituting Eqs. (2), (6), and (8) in (7) and taking into account the uncertainty due to A_1 and A_2, we obtain for the Gamow-Teller matrix element

$$\langle\sigma\rangle=+0.10\pm0.05. \qquad (9)$$

This result is consistent with the measured ft value[12] and

[9] *Nuclear Data Sheets*, compiled by K. Way *et al.* (Printing and Publishing Office, National Academy of Sciences—National Research Council, Washington 25, D. C., 1959), NRC 59-6.
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electron-neutrino angular correlation coefficient,[13] which set upper limits on $\langle\sigma\rangle$.

We now compare our experimental results with preliminary calculations based on Nilsson's rotational model.[14] Using the experimental value of $\langle\sigma\rangle$, Eq. (9), we find that the deformation parameter is

$$\eta(\mathrm{Ar}^{35}) = -2.3. \tag{10}$$

Mehta and Warke[15] have studied the angular distribution of protons from the reaction $\mathrm{Cl}^{35}(d,p)\mathrm{Cl}^{36}$. The value of the deformation parameter of Cl^{35} which they obtained by fitting the experimental angular distribution is $\eta(\mathrm{Cl}^{35}) = -2.8$. As expected, the mirror nuclei Ar^{35} and Cl^{35} have nearly the same deformation. The experimental magnetic moments and the magnetic moments predicted from Nilsson's model are compared in Table II. Possibly the large discrepancies between measured and calculated magnetic moments are due in part to pion exchange currents. The sum of the magnetic moments of mirror nuclei should be independent of such currents, however. In addition, there should be a spin orbit correction of about 0.2 nm to the Cl^{35} moment.[16] The corrected theoretical sum is then about 1.7 nm.

TABLE II. Experimental and theoretical values for the nuclear moments of Ar^{35} and Cl^{35}. The theoretical values are computed from the rotational model using a deformation parameter $\eta = -2.3$.

	Experimental	Theoretical
$\mu(\mathrm{Ar}^{35})$	+0.632 nm	+0.48 nm
$\mu(\mathrm{Cl}^{35})$	+0.821 nm[a]	+0.98 nm
$\mu(\mathrm{Cl}^{35})+\mu(\mathrm{Ar}^{35})$	+1.453 nm	+1.46 nm

[a] See Ref. 5, p. 615.

We plan to determine the asymmetries of Ne^{19} and Ar^{35} more precisely in future experiments.

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The Number Problem in Bardeen-Cooper-Schrieffer and Random-Phase-Approximation Nuclear Calculations*

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Use is made of the quasiboson method to study the problem arising from number nonconservation in applications of BCS methods to nuclear problems. This method neglects higher orders in $1/\Omega$, where Ω is an average number of available shell-model single-particle states. A method is given which identifies and removes number-dispersion spurious effects. The relation of this method to the prescriptions of Nogami and of Nilsson is discussed. An illustration of the method is given in an explicit calculation for the energy of a two-shell system in order Ω^2 and order Ω. It is shown that the projected BCS wave function method gives the leading order Ω^2 exactly and results in a good approximation to order Ω. Variation of the parameters of the projected wave function affords zero improvement in either order Ω^2 or Ω.

I. INTRODUCTION

In this paper use is made of the quasiboson method to consider the problems arising from the nonconservation of particle number in applications of Bardeen-Cooper-Schrieffer (BCS) solutions to nuclear problems. Considerations are limited to spherical systems of even numbers of nucleons.

The first step in many nuclear calculations is made by use of the BCS method,[1,2] which takes into account the most important parts of the pairing interactions. The remaining parts of the pairing interaction together with other, longer range, interactions remain as per-

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