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[1] L. Feldman and C. S. Wu, Phys. Rev. **76**, 180 (1949).
[2] R. E. Marshak, Phys. Rev. **75**, 513 (1949).

On the Spin and Beta-Spectrum of Cl^{36}*

C. LONGMIRE, C. S. WU, AND C. H. TOWNES
Pupin Physics Laboratories, Columbia University, New York, New York
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THE results presented in the preceding three letters may be used to eliminate much of the arbitrariness concerning the type of interaction in β-ray theory.

The recent discoveries of β-spectra (Y^{91}, Y^{90}, Sr^{90}, Sr^{89}, and Cs^{137}) having shapes which agree with theoretical shapes for the first forbidden transitions ($\Delta S=\pm 2$, yes) on the tensor (T) or axial vector (A) interaction are fair evidence that part of the true interaction must be either T or A, and agree with the apparent requirement of Gamow-Teller selection rules. However, these spectra give no information as to whether the two interactions contain any scalar (S), polar vector (V), or pseudoscalar (P) parts.

When the spectrum of Cl^{36} was first measured, it was noticed that the shape agreed very well with the theoretical spectrum for the second forbidden transition ($3\rightarrow 0$, no), again for T or A. However, since an apparently reliable measurement of the spin of Cl^{36} gives the value 2, we have tried to fit the spectrum with theoretical spectra for the transition $2\rightarrow 0$ (the final nucleus A^{36}, is even-even, and search indicated that there were no γ-rays). Table I shows the matrix elements which permit the transition $2\rightarrow 0$ with the associated parity changes. The correction factors (by which the "allowed" number of electrons must be multiplied) for these matrix elements have been given by Konopinski and Uhlenbeck, and by Greuling. Figure 1 shows that no single one of these correction factors agree with the experiment. For $2V$ and $2T$, there is some arbitrariness in the correction factor, since the ratio of the two possible matrix elements in each case may be varied. Thus, (e.g.) for $2T$ one may take

$$a(|T_{ij}|^2 \text{ shape})+b(|A_{ij}|^2 \text{ shape})+c(T_{ij}A_{ij} \text{ shape}),$$

where a, b, and c are arbitrary real numbers except that

$$a\geqslant 0, \quad b\geqslant 0, \quad c\leqslant 2(ab)^{\frac{1}{2}}.$$

(There are, of course, upper limits to the magnitudes of the matrix elements, but we have not relied upon them.) Even with this arbitrariness, one cannot fit the data. The closest possible fit with $2T$ is shown in Fig. 1; $2V$ would give almost identical results. Thus, no single interaction fits the experimental data.

The next step was to try combinations of interactions. Such combinations give cross-terms with new shapes. Fierz[1] found that the cross-terms seriously modified the shape of even allowed spectra if S is combined with V, or T with A; such combinations are therefore ruled out. Also, $2P$ will not combine with other second forbidden matrix elements, since P has opposite parity requirements. Therefore, in fitting the spectrum, one need try only combinations of two interactions at a time, namely ($2S$, $2A$) ($2S$, $2T$) ($2V$, $2T$) ($2V$, $2A$) ($2P$, $3V$).

We have calculated the correction factors for the first four of these combinations, using Marshak's spherical harmonic method. This work was rather tedious, but an excellent check was had by comparing the quadratic terms with their values as already given by Konopinski and Uhlenbeck.

TABLE I. Matrix elements which permit the transition $2\rightarrow 0$ with the associated parity changes.

Interaction	First forbidden	Second forbidden	Third forbidden
S		R_{ij} No	
V		R_{ij}, A_{ij} No	Yes
T	B_{ij} Yes	T_{ij}, A_{ij} No	
A	B_{ij} Yes	T_{ij} No	
P		$\gamma^5 R_{ij}$ Yes	

The results are shown in Fig. 2. The combinations ($2S$, $2T$) and ($2A$, $2V$) are almost identical and fit the data quite well. (In addition, these combinations will not alter spectra for Y^{91}, Y^{90}, Sr^{90}, Sr^{89}, and Cs^{137}.) For the combination (S, T) the data was best fitted by taking:

$$C_S R_{ij}=iC_T(0.175)A_{ij},$$
$$C_T T_{ij}=2iC_S R_{ij}.$$

It may be interesting to note that with this choice of the constants, the large $(\alpha Z/2\rho)^2$ and $2Z/\rho$ terms drop out of the correction factor; the result depends on the nuclear radius only through a factor multiplying the entire expression. For the ($2V$, $2T$) combination, we were able to fit the data only by arranging for an almost exact cancellation among all the ten curves available; we do not regard this fit as satisfactory, although we cannot rule out ($2V$, $2T$).

The last combination ($2P$, $3V$) was not worked, since ($2P$, $2V$) would not provide Gamow-Teller selection rules. In addition, the most reasonable guess is that the transition does not involve a change of parity, because the nucleons involved are presumably in D states.

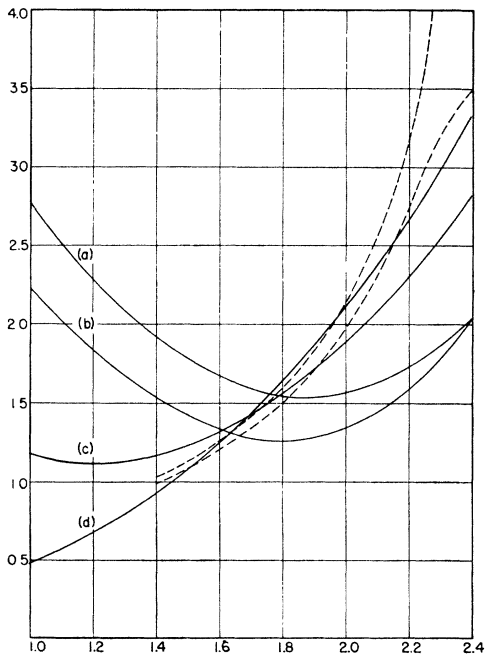

FIG. 1. Correction factors for Cl^{36} electrons. The area between the dashed curves represents the experimental data. Curve (a) is for $2T(T_{ij})$ and (approximately) $\frac{1}{2}2V(R_{ij})$; curve (b), same scale as (a), is for $2A(T_{ij})$ and (approximately) $\frac{1}{2}2S(R_{ij})$; curve (c) is for $2T(A_{ij})$ and $2V(A_{ij})$; curve (d) is best fit with $2T$, or $2V$ (approximately). The correction factor for $3V$ has roughly the same shape as (b). Ordinate scale is arbitrary.

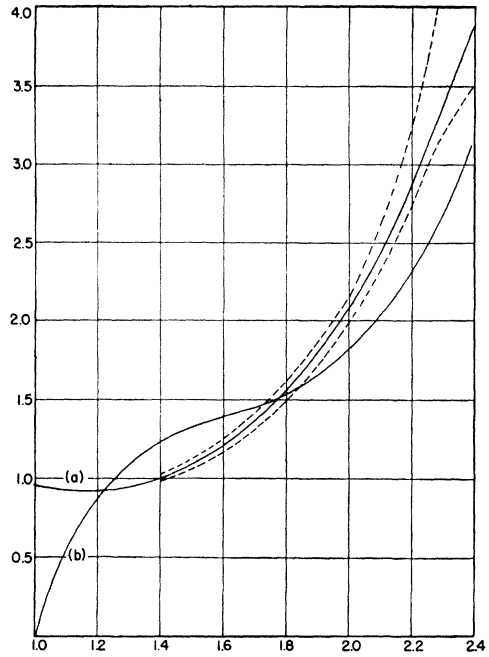

FIG. 2. Correction factors for Cl^{36} electrons. The area between the dashed curves represents the experimental data. Curve (*a*) is for the combination $(2S, 2T)$, or (approximately) for the combination $(2A, 2V)$. Curve (*b*) is the closest fit for the combination $(2S, 2A)$.

Summing the results, it seems that the forbidden spectrum of Cl^{36} cannot be explained by any single type of interaction and spin change of two. It can be interpreted by three of the combinations of interactions; namely, $(2S, 2T)$, $(2V, 2T)$, $(2V, 2A)$, but not by the combination $(2S, 2A)$. Moreover, these combinations of interactions give agreement with the observed spectra for Y^{91}, Y^{90}, Sr^{89}, Sr^{90}, and Cs^{137}.

The authors are indebted to Professors R. E. Marshak, G. E. Uhlenbeck, and E. P. Wigner for their valuable discussions and suggestions throughout this investigation and to Mrs. Zelda Droshnicop for her greatly appreciated assistance with the numerical calculations.

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[1] M. Fierz, Zeits. f. Physik **104**, 553 (1937).

Beta-Spectrum of Y^{91}

C. S. WU AND L. FELDMAN
Pupin Physics Laboratories, Columbia University, New York, New York
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THE beta-spectrum of Cl^{36} [1] was observed to be radically different from allowed shape or the forbidden type exhibited by RaE. An attempt was made to fit it with an $(p^2+q^2)^{\frac{1}{2}}$ [2] correction factor. This unique correction factor is the same as the one for transitions of $\Delta J = \pm 2$, (yes) as in Y^{91}, Y^{90}, Sr^{89}, Sr^{90}, etc.

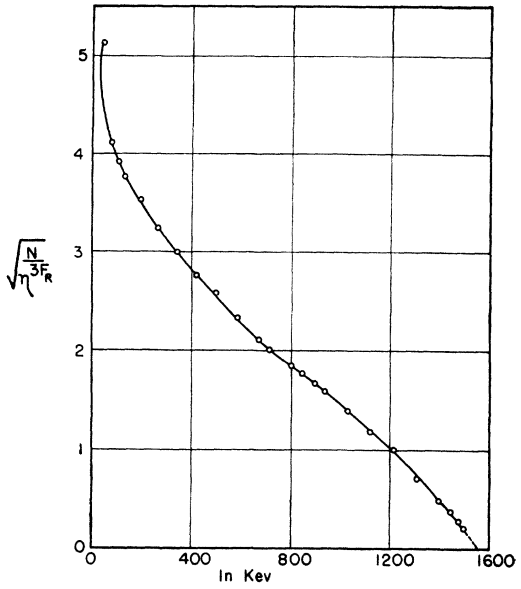

FIG. 1. Conventional Fermi plot for Y^{91} beta-spectrum.

However, the difference between the two curves is quite pronounced. In order to check the distinctiveness of these two forbidden shapes, the beta-spectrum of Y^{91} was investigated in the solenoid magnetic spectrometer under conditions identical with those for the investigation of Cl^{36}, except that the thickness of the Y^{91} source was less than 100 mg/cm^2. Baffle systems of resolution of 2.5 percent and 4 percent both were used and yielded identical results.

Figure 1 is a Fermi plot of the Y^{91} beta-spectrum treated as an allowed transition. This curve shows a definite inversion point around the energy region of 500 kev as expected from the $(p^2+q^2)^{\frac{1}{2}}$ correction factor, but the concavity of the curve at the high energy region is much less pronounced than in the case of Cl^{36}.

When each point of the curve in Fig. 1 is divided by its corresponding $(p^2+q^2)^{\frac{1}{2}}$ correction factor all the points thus calculated fit a straight line, as shown in Fig. 2, from the upper energy limit

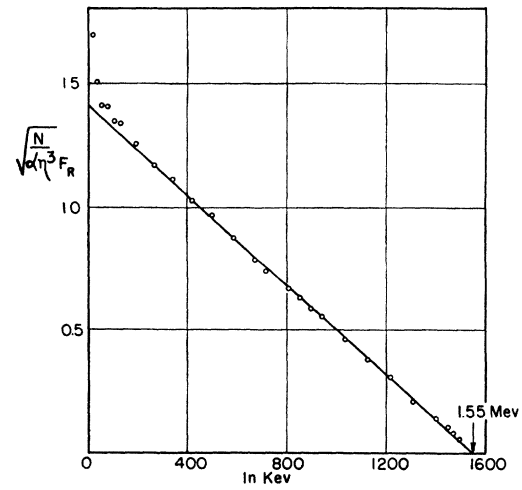

FIG. 2. Fermi plot of Y^{91} corrected by $(\alpha)^{\frac{1}{2}} \sim [(\epsilon^2-1)+(\epsilon_0-\epsilon)^2]^{\frac{1}{2}}$.