mentally by measuring the ratio of the radiations from extremely thin Cl^{36} and RaE sources deposited on collodion films of ~12 microgram/cm² when they are either backed or not backed with the standard silver disks.

The absorption in the counter window and the air path between the source and the counter and also the self-absorption of the source are corrected by extrapolating the beginning of the absorption curve to zero thickness. Since the curvature of the absorption curve at the beginning is small, the error introduced in extrapolating should not be appreciable.

Five different sources were prepared from two different batches of HCl. The half-life determinations are listed in Table I.

The half-life of sample *b* was also determined in a low absorption counter[5] giving good agreement with the above result. We conclude that the half-life of Cl^{36} is $(0.44\pm0.05)\times10^6$ yr., where the error of approximately 10 percent is thought to include possible systematic errors.

To recheck the possibility of positron emission in a Cl^{36} source, a strong $LiCl^{36}$ source was placed in the spectrometer and the energy region from 20 kev to 700 kev carefully scanned for electrons and positrons. Figure 1 shows that when the spectrometer is adjusted for positrons, the counting rate remained at background throughout the whole energy region in spite of the high electron activity. Judging from the ratio of the areas under the electron curve and the positron curve, the ratio of positrons to electrons emitted is less than 10^{-4}. Although positrons from Cl^{36} were observed[2] in the cloud chamber, observations of numerous positron tracks from a thick pure electron emitter such as P^{32} in a cloud chamber have been frequently reported in the literature, but these positron tracks seem to disappear[6] when a thin source is used.

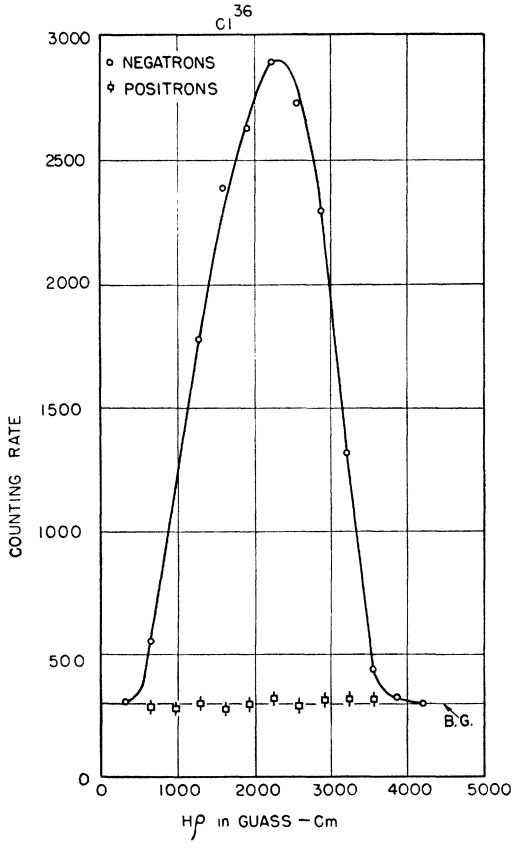

FIG. 1. Search of positrons from Cl^{36} by beta-ray spectrometer.

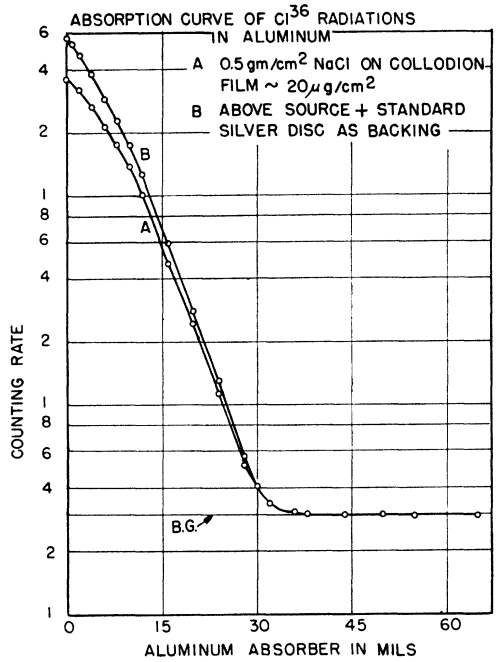

FIG. 2. Absorption curves of Cl^{36} radiations in aluminum.

The absorption curve of the Cl^{36} beta-radiation in Al foils is shown in Fig. 2. Curve A shows the absorption curve of a Cl^{36} source on a thin collodion film; curve B is the absorption curve of the same Cl^{36} source except with the standard silver disk right behind the collodion film. The steeper initial slope of curve B is probably due to the softness of the back-scattered radiation. At 38 mils of Al, both curves show only background counts which give the upper energy limit of 0.73 Mev in good agreement with the spectrometer determination of 0.713 Mev. For absorber thicknesses greater than 38 mils of Al, no point lies outside of the statistical fluctuations of the background rate which is 0.02 percent of the total number of counts. Therefore, no gamma-rays are associated with the disintegration of Cl^{36} unless they are of very low energy (<20 kev) or of low intensity (<5 percent of disintegration if gamma-ray were of the order of 1 Mev).

* Work supported jointly by the AEC Contract AT-30-1-Gen 72, the Signal Corps and the ONR.

[1] Overman (Radioactivities Produced in Neutron Irradiation of Chlorine), AECD 857.
[2] D. C. Grahame and H. J. Walke, Phys. Rev. **60**, 909 (1941).
[3] Hughes, Eggler and Goldstein, P. P. R., CP-3801, p. 17 (1947).
[4] F. Johnston and J. E. Willard, Phys. Rev. **75**, 528 (1949).
[5] L. D. Norris and M. G. Inghram, Phys. Rev. **73**, 350 (1948).
[6] Bradt, Heine and Scherrer, Helv. Phys. Acta. **16**, 491 (1943). L. Smith and G. Groetzinger, Phys. Rev. **70**, 96 (1946). T. H. Pi and C. Y. Chao, Phys. Rev. **72**, 639 (1947).

The Beta-Ray Spectrum of Chlorine[36]*

C. S. WU AND L. FELDMAN
Pupin Physics Laboratories, Columbia University, New York, New York
July 18, 1949

RECENTLY, a strong source of radioactive Cl^{36} was obtained from the Atomic Energy Commission Isotope Division at Oak Ridge. The specific activity of the chlorine was given as 0.0003 mc/mg which is high enough to permit an investigation of its β-spectrum. The new baffle system[1] of the solenoid magnetic

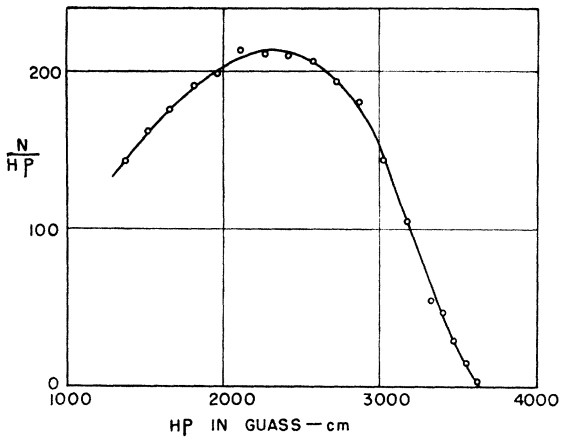

FIG. 1. Momentum distribution of Cl^{36} beta-spectrum. Thickness of the $LiCl^{36}$ source is around 0.3 mg/cm².

β-spectrometer of Columbia University designed according to the ring-focus principle offers a large transmission of the electron beam of 6 to 7 percent with a resolution of 4 percent, defined as the full width at half-maximum intensity. Under these favorable conditions, a Cl^{36} β-ray source of the order of magnitude of 0.01 μc will yield a reasonably accurate spectrum without special efforts. The radioactive chlorine is supplied by Oak Ridge in the form of an HCl solution. It is a by-product of the production of S^{35} ($Cl^{35}(n,p)S^{35}$). The HCl solution is neutralized to LiCl and chemical separation of S^{35} is carried out. Several LiCl sources varying from 300 μg/cm² to 1 mg/cm² were used in this investigation. Both collodion and Nylon window counters were used to cover the whole range. Figure 1 shows the momentum distribution curve of Cl^{36} β-spectrum. It is interesting to note that the maximum of the distribution is shifted more to the higher energy region than is expected from a symmetrical distribution curve. For an element of low atomic number such as Cl^{36}, the allowed beta-ray momentum distribution curve should be fairly symmetrical. The effects of the Coulomb correction or of the slowing down of electrons in the source itself would be to shift the maximum of the curve to the lower energy region. A superposition of two β-spectra would also cause a shift opposite to the one actually observed. Figure 2 shows the conventional Fermi plot of the Cl^{36} data treated as an allowed transition. The Fermi plot exhibits pronounced curvature toward the energy axis down to the very low energy region. This is the first shape of this kind ever observed among the forbidden spectra. The marked curvature between the upper energy limit down to ~180 kev was identical within the experimental uncertainty for sources varying in thickness from 300 μg/cm² to 1 mg/cm². The energy region below 180 kev was not extensively investigated as its true shape is probably distorted by the comparatively unfavorable source thickness used. A Cl^{36} source of higher specific activity would be preferred for this low energy region.

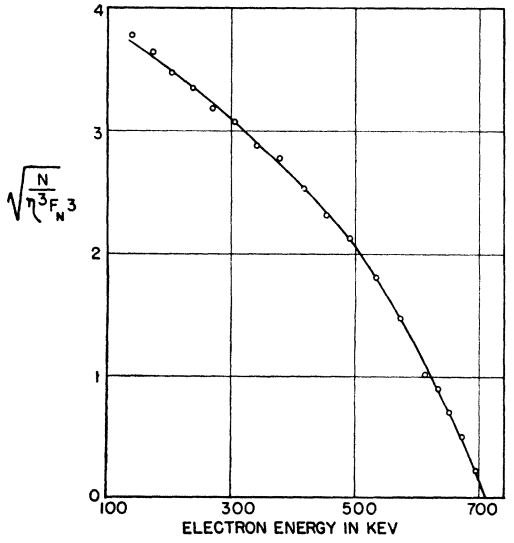

FIG. 2. Conventional Fermi plot for Cl^{36} beta-spectrum.

The spin of Cl^{36} was not known when the β-spectrum of Cl^{36} was first observed. Following the usual procedure of interpreting a forbidden shaped spectrum, a perfect fit (see Fig. 3) was found

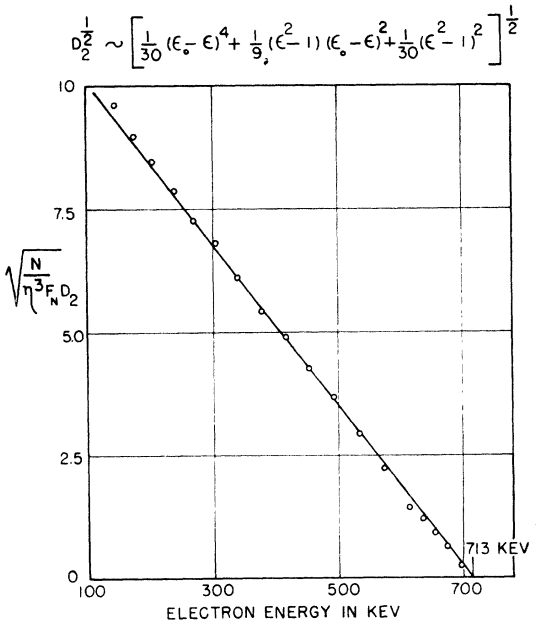

FIG. 3. Forbidden Fermi plot for Cl^{36} beta-spectrum. The D_2 correction factor is used.

between the observed spectrum and the so-called D_2 correction factor (using Marshak's notation)[2] which is the unique forbidden correction factor predicted by Marshak for Be^{10}, a transition where the spin change is ± 3. Moreover, Cl^{36} has approximately the same half-life and upper energy limit as Be^{10}. Theoretically, it would have been considered a parallel case to that of Be^{10} if the spin change were not known. C. H. Townes has recently determined the spin of Cl^{36} by comparing the microwave spectrum of $Cl^{36}CN$ with the theoretical patterns of several values of nuclear spin of Cl^{36} (refer to the Letter to the Editor by C. H. Townes and L. C. Aamodt). The spin of Cl^{36} determined from his experiments is definitely 2. Since argon 36 contains an even number of both neutrons and protons, its spin is probably zero. With a spin change of 2, and parity change either yes or no, a β-transition can be any one of the many transitions as allowed by the selection rules. The correction factors of all possible transitions were calculated and the ratios of the nuclear matrix elements were adjusted to try to fit the experimental spectrum. Refer to the letter following this one. But no fitting between the theoretical and experimental curves could be considered as satisfactory as that given by the D_2 factors or the correction factors from the linear combinations of S and T, V and A, and V and T interactions.

The authors wish to thank Professor J. R. Dunning, Dr. W. W. Havens, Jr., and Dr. L. J. Rainwater for their constant interest and encouragement. We are also indebted to Mrs. Zelda Droshnicop for her assistance with the numerical calculations.

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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
July 18, 1949

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.

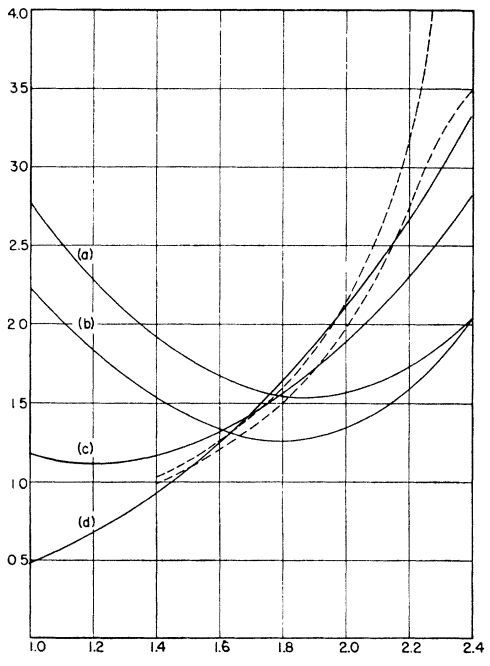

FIG. 1. Correction factors for Cl^{36} electrons. The area between the dashed curves represents the experimental data. Curve (a) is for $2T(T_{ij})$ and (approximately) $\frac{1}{2}2V(R_{ij})$; curve (b), same scale as (a), is for $2A(T_{ij})$ and (approximately) $\frac{1}{2}2S(R_{ij})$; curve (c) is 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.