thought to be Fr^{212}.[28] It was assigned to At^{208} principally on the basis of the appearance of Po^{208} at the rate corresponding to the decay of a 1.8 hr. parent. It may be mentioned that by spallation reactions of bismuth another apparent astatine parent of Po^{208} is produced which decays with a longer half-life than 1.8 hrs. and has no observable alpha-radiation.[72] It is possible that there are isomers of At^{208} which show up in different abundances by the two modes of formation.

Through excitation function measurements a 5.76 Mev alpha-particle decaying with 1.8-hr. half-life has been assigned to At^{207}.[72] Two other probable astatine isotopes are assigned to At^{205} and At^{204} somewhat arbitrarily although the mass number range is defined by excitation experiments. The two activities are respectively a 25-min. period of 5.9 Mev alpha-energy and a 10-min. period with a 6.1 Mev alpha-particle.[72]

Po^{209}

This new isotope of polonium has a 200-year half-life for alpha-decay estimated from yield considerations[71] and the alpha-particle energy has been revised slightly as 4.90 Mev.[73] The electron capture branching is not known accurately but was estimated from the amount of L-x-rays as a maximum of 1 in 10.[24] The electron capture half-life would be accordingly greater than 2000 years.

Po^{205} and lighter polonium isotopes

As in the case of light astatine isotopes there is little accurate information on the alpha-half-lives of these species and the isotopic assignments are not certain. The energies are sufficiently well known and the isotopic assignments are well enough defined for use in Fig. 1 to show the trend expected in this region. The presently accepted decay properties of Po^{205} are a measured half-life of 1.5 hr. with a 5.2 Mev alpha-particle.[24] The 5.35 Mev alpha-particle with 4-hour half-life[3] has been reassigned to Po^{204},[24] while the 40 min., 5.56 Mev alpha-emitter is retained at Po^{203}. In each case the degree of alpha-branching is not known.

[73] A. Ghiorso, unpublished data.

Bi^{208}(?)

In a previous communication[10] a 5.0 Mev alpha-particle found by Howland and Perlman (unpublished) was attributed to Bi^{208}. This alpha-particle appeared as a very weak activity in the bismuth fraction of pile neutron irradiated bismuth and was thought to arise from an $n,2n$ reaction. This assignment was not very attractive since we might expect Bi^{208} to have an alpha-energy not greater and perhaps less than that of Bi^{209}. The interesting possibility is being explored[74] that the 5.0 Mev alpha-group belongs to a metastable state of Bi^{210}(RaE) highly forbidden toward isomeric transition and beta-decay. Partial but inconclusive evidence for this assignment has been obtained.

Bi^{201}

The 60-min. activity with alpha-particles of 5.15 Mev assigned to Bi^{200} [3] has been reassigned to Bi^{201} on the basis of its genetic relationship to 8-hr. Pb and 72-hr. Tl which are tentatively assigned to mass number 201.[21]

Bi^{199}

This is the only one of the neutron deficient bismuth alpha-emitters for which the alpha-branching has now been estimated. Its isotopic assignment has been made[21] by observing the growth through successive electron capture processes of Pb^{199} and the 7.5-hr. Tl^{199}. The alpha-branching calculated from the yields of the Tl^{199} and the observed alpha-emission rate is 1.7×10^{-3} percent which gives an alpha-half-life of 3 years.

Bi^{197}

This 2-min. activity assigned to Bi^{197} is used in these correlations in terms of its minimum alpha-half-life by assuming that the measured half-life is controlled by the alpha-decay process.

Au^{190}

This alpha-emitter[3] has been more positively identified as an isotope of gold and by measuring the other radiation decaying with a 5-min. half-life, the alpha-branching was estimated as 10^{-2} percent.[23]

[74] Neumann, Howland, and Perlman, unpublished data.

PHYSICAL REVIEW VOLUME 77, NUMBER 1 JANUARY 1, 1950

The Beta-Spectra of Cl^{38}*

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(Received September 23, 1949)

The beta-spectra of the 38-min. activity of Cl^{38} was studied in a magnetic lens spectrometer. The momentum distribution was resolved into three groups with end points of 4.81, 2.77, and 1.11 Mev. The highest energy group was found to have a shape characteristic of a once forbidden transition involving a spin change of 2 units and a change of parity.

INTRODUCTION

THE 38-min. activity of Cl^{38} has been studied by many investigators.[1] Most recent measurements with magnetic spectrometers have been made by Hole and Siegbahn[2] and by Watase and Itoh.[3] In both cases, the beta-transition was found to be complex with at least two and probably three groups of electrons.

By means of a Fermi plot analysis, Hole and Siegbahn arrive at end points of 1.19, 2.70, and 5.2 Mev. However, because of the effect of saturation in the iron of their spectrometer, they express some uncertainty about the accuracy of the high energy group which in turn raises some doubts about the exact determination of the inner end points. They prefer, therefore, to base the value of the beta-end points upon the energy measurement of the two cascade gamma-rays which they measure as 1.60 Mev and 2.15 Mev. They assume that the energy determination of the lowest beta-group is

* This document is based on work performed under government Contract No. W-7405-Eng-36 for the Los Alamos Scientific Laboratory of the University of California.
** Indiana University, Bloomington, Indiana.
[1] Complete references to earlier work may be found in reference 2.
[2] N. Hole and K. Siegbahn, Arkiv. f. Mat., Astr. o. Fys. **33A**, No. 9 (1946).
[3] Y. Watase and J. Itoh, Proc. Phys. Math. Soc. Japan **30**, 626 (1939).

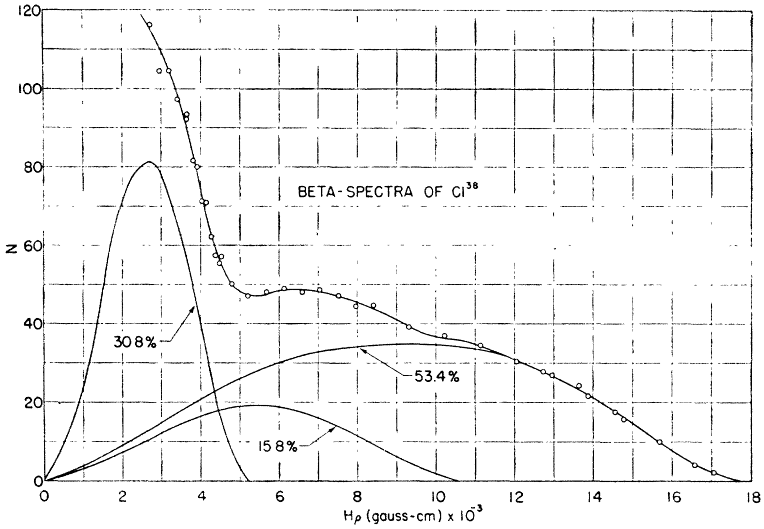

FIG. 1. Momentum distribution of electrons of Cl^{38}. Ordinate is counting rate divided by coil current.

correct. In this way, they obtain 1.19, 2.79, and 4.94 Mev.

By inspection of the momentum distribution, Watase and Itoh find end points at 4.99±0.06 Mev and at about 1.1 Mev. On the basis of a Fermi plot, they report 4.99, 1.08±0.06 and probably a third group at 2.6 Mev. From the distribution of the Compton electrons ejected from a radiator, Itoh[4] has determined the energy of the gamma-rays as 1.64±0.02 Mev and 2.19±0.03 Mev. Coincidence experiments indicate that these gamma-rays are in cascade.

In both investigations, the Fermi plots of the beta-spectra were interpreted as being of the allowed shape and a straight line extrapolation was made on that basis. The results of the present study indicate that the highest energy group has a spectrum of the once forbidden type; the conventional Fermi plot curves toward the energy axis near the end point. The evaluation of this and the lower end points is changed somewhat by this interpretation of the data.

EXPERIMENTAL METHOD

Measurements were made with a large thin lens spectrometer. Preliminary experiments indicated that a rather strong dipole field was being induced in the reenforced concrete of the floor beneath the lens. This trouble was eliminated by banding the spectrometer tube with iron rings in accordance with the suggestion of L. W. McKeehan.[5] One-inch wide transformer iron wound to a thickness of $\frac{1}{8}$ in. and spaced $\frac{1}{2}$ in. apart was employed. This arrangement was found to be quite effective in eliminating interference from all external vertical fields including that of the earth. Under these conditions, it was found that, in spite of the presence of iron, the magnetic focusing field was linearly proportional to the coil current to much better than one percent over the entire range of the instrument, i.e., up to $H\rho=46{,}000$ gauss-cm.

Appropriate baffles and diaphragms were installed, which minimized the possible detection of scattered radiation and of harmonic spectra. A pair of sector baffles which are very effective in discriminating between positrons and electrons, are also of value in suppressing harmonic spectra. These bafflels consist of two identical $\frac{3}{4}$-in. thick aluminum disks each having two diametrically opposed sector openings of just a little less than 90 degrees each. The disks are rotated on their common axis through 45 degrees with respect to each other and spaced experimentally by means of a Wilson-type vacuum seal so as to offer optimum discrimination. Although the transmission of the instrument is reduced somewhat by this arrangement, it is felt that there is less opportunity for scattering than exists with the spiral or "paddlewheel" type baffle.[6]

For the present experiment, the detecting diaphragm opening and the source diameter were 0.75 in. For these conditions, it was found that the resolution, as determined by the full width at half-maximum of the line of internal conversion electrons associated with the 0.663-Mev gamma-ray which follows the decay of Cs^{137}, could be varied from 2.4 to 6.4 percent by setting the position of a disk baffle. This baffle limits the effective annular aperture of the lens. The energy calibration of the instrument is in terms of this 0.663-Mev gamma-ray.

The source was mounted on a skeleton aluminum framework which could be brought accurately and quickly into its proper position through a vacuum gate. The source itself consisted of 10 mg/cm² of NH_4Cl uniformly deposited over a 0.75-in. diameter circle on a 0.0002-in. Al backing. Such a source thickness and backing may be regarded as "thin" for the high energy electrons here under investigation.

Activation was obtained by slow neutron capture in

[4] J. Itoh, Proc. Phys. Math. Soc. Japan **23**, 605 (1941).
[5] D. E. Alburger, Rev. Sci. Inst. **19**, 474 (1948).
[6] Deutsch, Elliot, and Evans, Rev. Sci. Inst. **15**, 178 (1944).

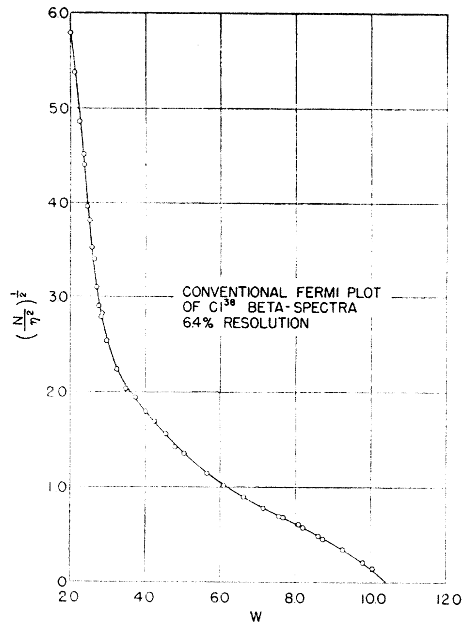

FIG. 2. Conventional Fermi plot of Cl^{38} data. The energy W is in units of m_0c^2.

the thermal column of a nuclear reactor. The same source was used for several bombardments. Measurement of the decay period showed that there was no interference from other activities, e.g., the excitation of 14.8-hr. Na^{24} in the aluminum backing by $Al(n, \alpha)$ was completely negligible.

Detection was by means of a 3.5-mg/cm² mica end window G-M counter. The counter was found to be completely stable and gave reproducible results when operated after the one-hour "warm-up" required to assure drift-free operation of the electronic lens current stabilizer.

RESULTS

Figure 1 shows the momentum distribution of the electrons emitted by Cl^{38}. The ordinate, of course, is the actual counting rate divided by the current, in order to normalize to constant detection sensitivity. From the shape of the curve, it is quite obvious that the distribution is composed of three superposed spectra.

Figure 2 shows the conventional Fermi plot of the data applicable to allowed transitions. The usual Coulomb factor is not shown in the ordinate since for such a low Z element, it is a very good constant over the energy range covered by the data. Careful examination of the points near the maximum energy suggest that the data do not fall on a straight line but rather on a curve which is concave toward the energy axis. If the last two points were corrected for the finite resolution of the instrument, they would be shifted so as to appear with the same ordinate at slightly lower values of the energy. This would make the curvature even more obvious. A curvature of this nature does indeed also occur in the Fermi plot of the data of Hole and Siegbahn.[2] They, however, apparently chose to ignore it, probably because of the previously mentioned saturation effect in the iron of the spectrometer.

Figure 3 shows Fermi plots of the data on the highest energy group obtained with 2.4 percent resolution. The lower curve is the conventional Fermi plot and shows the curvature quite clearly. The upper curve was obtained by dividing the ordinate by the factor $C^{\frac{1}{2}} \sim [W^2 - 1 + (W_0 - W)^2]^{\frac{1}{2}}$. This factor uniquely determines the shape of a once-forbidden transition involving a change

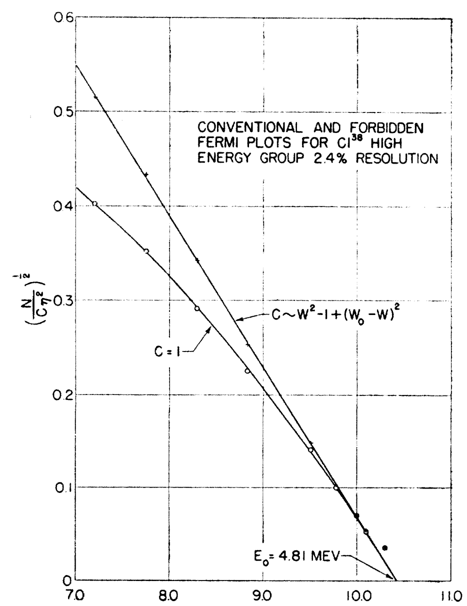

FIG. 3. Conventional and forbidden Fermi plots of Cl^{38} data obtained with 2.4 percent resolution.

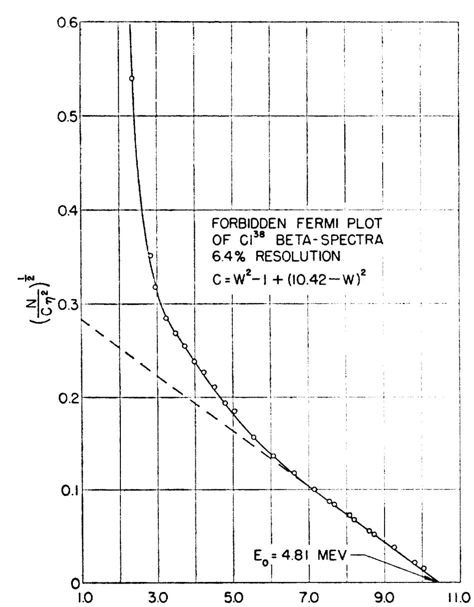

FIG. 4. Forbidden Fermi plot of Cl^{38} beta-spectra.

of two units of angular momentum and a parity change.[7] The end point of the high energy group determined from this plot is 4.81 ± 0.05 Mev. A similar forbidden Fermi plot for all the data obtained at 6.4 percent resolution is shown in Fig. 4. Assuming that only the highest energy group is of the forbidden type, the lower energy groups are separated by proper subtraction as indicated in Fig. 5. The additional end points obtained in this way are 2.77 ± 0.05 Mev and 1.11 ± 0.01 Mev. The partial spectra determined from the Fermi plots are shown in Fig. 1.

DISCUSSION

The fact that the highest energy group has a spectrum which is completely described by applying the once-forbidden factor $W^2-1+(W_0-W)^2$, does not, in this case, uniquely determine that the change of angular momentum is 2 units. In general, according to G-T selection rules, a once-forbidden transition involves a change of parity and may have either 0, 1, or 2 units of angular momentum change. The forbidden factor C, which may modify the shape of the spectrum, may be written[8] as

$$C(W,Z)=\frac{a'}{18}(P_e^2+P_\nu^2)+\tfrac{2}{3}b'P_\nu\left(\frac{\alpha Z}{2R}+\frac{P_e^2}{3W}\right)+c'\left(\frac{\alpha^2Z^2}{4R^2}+\frac{\alpha Z}{3R}\frac{P_e^2}{W}\right),$$

where $P_e^2=W^2-1$ and $P_\nu^2=(W_0-W)^2$. For a spin change of 0 or 1, all three constants a', b', and c' are finite. For elements of medium to high atomic number, Z, the term $\alpha^2Z^2/4R^2$ is much larger than the others and the factor is not very energy dependent. As a result, one may expect such transitions to have spectrum shapes indistinguishably different from those of allowed transitions. However, for once-forbidden transitions involving a spin change of 2 units, only the constant a' remains finite and the characteristic shape described above is obtained. On the other hand, the existence of this shape does not uniquely assure that the spin change in Cl^{38} is 2 units. This arises from the fact that for such a low Z and high energy, is is conceivable that the second and third terms in the forbidden factor might be vanishingly small compared to the first term. Thus, the possibility of a spin change of 0 or 1 is not completely excluded on this basis alone.

According to the theory of nuclear shell structure,[9] one may expect for the ${}_{17}Cl^{38}$ nucleus that the odd proton will be in a $d_{3/2}$-state and the odd neutron in a $f_{7/2}$-state. These may combine to give a state of odd parity having a resultant spin of either 2, 3, 4, or 5. The product nucleus, ${}_{18}A^{38}$ has an even number of protons and neutrons and is therefore expected to have

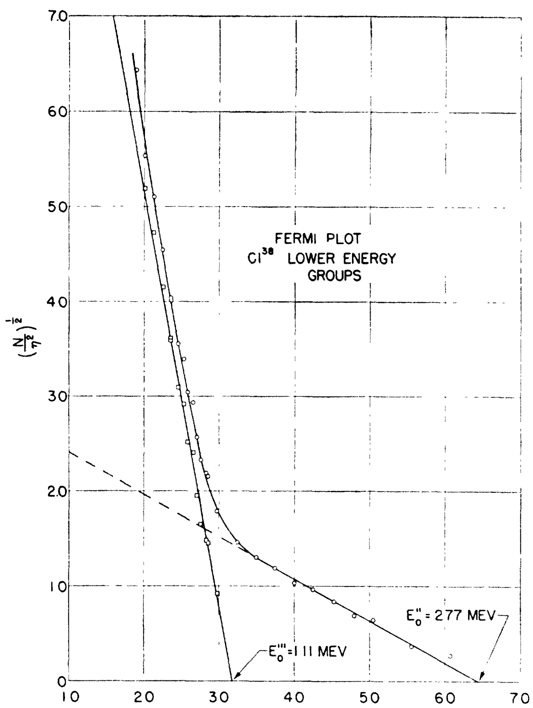

FIG. 5. Fermi plot of lower energy groups of Cl^{38} beta-spectra.

zero spin and even parity. A spin change of two units is, therefore, the only value consistent with both experiment and theory. The comparative half-life ($ft\sim2\times10^7$) is also reasonable for a once-forbidden transition from Cl^{38} involving a spin change of 2.

CONCLUSION

The beta-disintegration of Cl^{38} is complex and consists of three groups. The end-point energies and the branching ratios are: 4.81 ± 0.05 Mev, 53.4 percent; 2.77 ± 0.05 Mev, 15.8 percent; 1.11 ± 0.01 Mev, 30.8 percent. The highest energy group was found to have a spectrum shape which is characteristic of a once-forbidden transition involving a spin change of two units and a change of parity. In agreement with the theory of nuclear shell structure this is presumably a transition from the state of ${}_{17}Cl^{38}$ having spin 2 and odd parity to the ground state of ${}_{18}A^{38}$ having even parity and zero spin. The intermediate group of electrons with end-point energy of 2.77 Mev has a comparative half-life ($ft\sim10^7$) which is reasonable for a once-forbidden transition having a spin change of 0 or 1. This spectrum is apparently of the allowed shape. The beta-transition having an end point of 1.11 Mev is allowed ($ft\sim10^5$). Therefore, it goes to a level of odd parity. Since the "cross-over" gamma-ray directly to the ground state is not observed, the spin of the second excited level in A^{38} is probably 3. From the beta-ray measurements alone, the excited levels in A^{38} lie at 2.04 Mev and 3.70 Mev above the ground state.

Thanks are due Mr. R. J. S. Brown and Mr. L. M. Baggett for assisting with the measurements.

[7] L. M. Langer and H. C. Price, Jr., Phys. Rev. **75**, 1109 (1949). L. M. Langer and H. C. Price, Jr., Phys. Rev. **76**, 641 (1949).
[8] G. Gamow and C. L. Critchfield, *Theory of Atomic Nucleus and Nuclear Energy-Sources* (Oxford University Press, New York, 1949), p. 139.
[9] M. G. Mayer, Phys. Rev. **75**, 1969 (1949).