Electron-Neutrino Angular Correlation in the Beta Decay of Neon[19]†*

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The electron-neutrino angular correlation in the beta decay of Ne^{19} has been measured by observing the energy spectrum of F^{19} recoil ions. The constant λ in the angular correlation function $[1+\lambda(v_e/c)\cos\theta_{e\nu}]$ was found to be $\lambda=-0.21\pm0.08$, indicating that the beta-decay interaction is of the form *STP* and not *VTP*. The observed angular correlation leads to the result

$$C_S^2\left|\int 1\right|^2 \Big/ C_T^2\left|\int \boldsymbol{\sigma}\right|^2=0.69\pm0.17,$$

which is consistent with $C_S^2\simeq C_T^2$ if the nuclear configuration is $(d_{5/2})^3{}_{1/2}$, but not if the configuration is $(s_{1/2})^3{}_{1/2}$. Most of the F^{19} recoils carried one unit of negative charge, but singly charged positive ions were also detected. The coincidence rate due to positive ions was about 10 percent of that due to negative ions. No doubly charged recoils were observed.

I. INTRODUCTION

RECENT measurements[1,2] of the electron-neutrino angular correlation in the beta decay of He^6 have indicated that the beta-decay interaction includes a tensor component and that the axial vector component is small or zero. The interaction must also include a scalar or (polar) vector component, as has been recognized since the discovery[3,4] of allowed $J=0\rightarrow 0$ transitions in the decay of C^{10}, O^{14}, and Cl^{34}. The principal objective of this experiment was to identify the Fermi (S or V) part of the interaction by measuring the angular correlation in an allowed transition of the type $\Delta J=0$, with no change of parity.

The most general interaction (excluding derivatives of wave functions), consistent with the requirement of relativistic invariance of the interaction Hamiltonian, is the linear combination

$$H'(\beta)=G[C_SH_S'+C_VH_V'+C_TH_T'+C_AH_A'+C_PH_P'],\quad (1)$$

where

$$C_S^2+C_V^2+C_T^2+C_A^2+C_P^2=1,\quad (2)$$

and the subscripts refer to the five "pure" interactions Scalar, Vector, Tensor, Axial Vector, and Pseudoscalar. The transition probability for allowed beta decay with an interaction Hamiltonian of the form (1) has been calculated by de Groot and Tolhoek.[5] If there is no Fierz interference, the decay probability is proportional to $[1+\lambda(v_e/c)\cos\theta_{e\nu}]$, where v_e is the speed of the electron, $\theta_{e\nu}$ is the angle between the directions of emission of the electron and the neutrino, and λ is given by[6]

$$\lambda=\frac{(C_S^2-C_V^2)\left|\int 1\right|^2-\frac{1}{3}(C_T^2-C_A^2)\left|\int \boldsymbol{\sigma}\right|^2}{(C_S^2+C_V^2)\left|\int 1\right|^2+(C_T^2+C_A^2)\left|\int \boldsymbol{\sigma}\right|^2}.\quad (3)$$

The assumption of no Fierz interference, as justified by the linear Kurie plots obtained for several allowed beta transitions,[7–9] leads to the conclusion that the interaction cannot include both S and V, nor can it include both T and A. The results of the He^6 recoil experiments then indicate that the interaction is either *STP* or else *VTP*, where the pseudoscalar component probably should be included to account for the shape of the RaE beta spectrum.[10] Substitution of $C_A=0$ and either $C_S=0$ or $C_V=0$ in (3) reveals that if the Fermi component is S, then $-1\leq\lambda<\frac{1}{3}$, whereas if this component is V, then $\frac{1}{3}<\lambda\leq 1$. The interaction type can therefore be determined uniquely by a measurement of the angular correlation in a transition obeying Fermi selection rules. In transitions with $\Delta J=0$, $J\neq 0$, the angular correlation is dependent on both the Fermi (F) and Gamow-Teller (G-T) interaction components, and consequently the experimental results may be used not only to distinguish between the possible interaction types, but also to determine the relative magnitudes of the F and G-T components.

The angular correlation constant λ can be determined by observing coincidences between the beta particles and the recoil ions, the most direct procedure

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[2] B. M. Rustad and S. L. Ruby, Phys. Rev. **89**, 880 (1953).

[3] Sherr, Muether, and White, Phys. Rev. **75**, 282 (1949); R. Sherr and J. B. Gerhart, Phys. Rev. **91**, 909 (1953).

[4] W. Arber and P. Stähelin, Helv. Phys. Acta. **26**, 433 (1953).

[5] S. R. de Groot and H. A. Tolhoek, Physica **16**, 456 (1950).

[6] In Eq. (3) the negligibly small terms corresponding to the pseudoscalar component have been omitted.

[7] H. M. Mahmoud and E. J. Konopinski, Phys. Rev. **88**, 1266 (1952).

[8] J. P. Davidson and D. C. Peaslee, Phys. Rev. **91**, 442 (1953); Phys. Rev. **91**, 1232 (1953); Phys. Rev. **92**, 1584 (1953).

[9] O. Kofoed-Hansen and A. Winther, Phys. Rev. **89**, 526 (1953). These authors have emphasized that the possibility of appreciable Fierz interference is not ruled out by the available experimental evidence.

[10] A. Petschek and R. Marshak, Phys. Rev. **85**, 698 (1952).

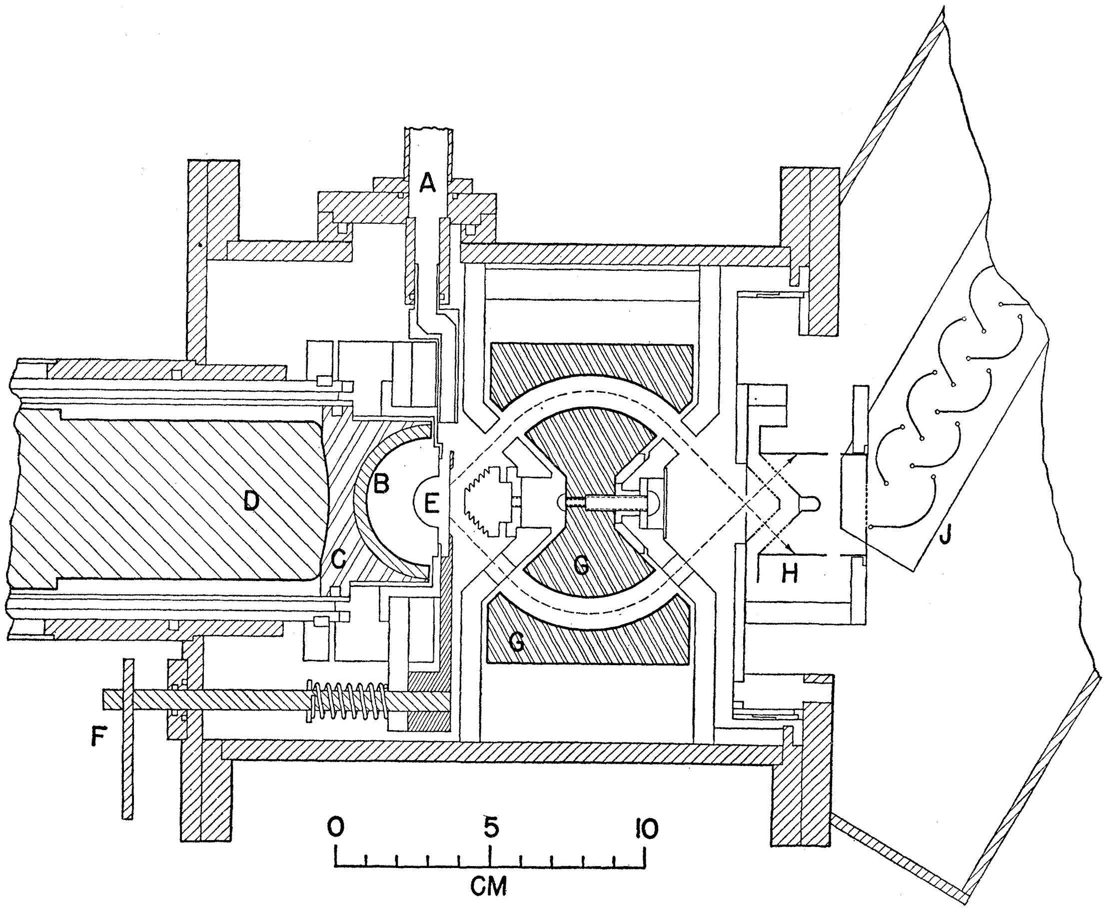

FIG. 1. Cross section of recoil chamber showing electrostatic spectrometer and detectors.

being to measure the coincidence rate as a function of the angle between the momentum vectors of these two particles. Alternatively, the coincidence rate can be observed as a function of the energy of one of the particles and the value of λ inferred from the shape of the resultant spectrum. The latter method has the advantage that the detectors can be made to subtend very large solid angles at the source, thus decreasing the running time required for a given statistical accuracy. In this experiment the energy spectrum of the recoil ions was observed, using an electrostatic spectrometer as an energy selector for the recoils.

The selection of a suitable isotope for investigation was limited by the requirement that the source be in the form of a (preferably monatomic) gas which could be produced by cyclotron bombardment and separated readily from the target material. The decision was made to use Ne^{19}, a positron emitter which undergoes a superallowed mirror transition with $J=\frac{1}{2}\rightarrow\frac{1}{2}$. The maximum kinetic energy of the positrons is 2.18 ± 0.03 Mev and the half-life is 18.5 ± 0.5 seconds,[11] corresponding to $ft\simeq2000$ sec. The beta spectrum is simple and has an allowed shape.[11–13] The maximum kinetic energy of the F^{19} recoil ions is about 200 electron volts.

II. APPARATUS AND PROCEDURE

A. Description of Apparatus

Ne^{19} was produced in the reaction $F^{19}(p,n)Ne^{19}$ by the bombardment of SF_6 gas with 6-Mev protons from the University of Illinois cyclotron. After separation from the SF_6, the neon was admitted to the recoil chamber, where the normal operating pressure was about 5×10^{-6} mm Hg. A vertical cross section of the chamber is shown in Fig. 1. The radioactive gas entered the chamber through tube A and diffused throughout the vacuum system, but useful data were provided only by those disintegrations which occurred within the "source volume" (E), a region approximately 2 cm³ in volume located between the electron detector and the electrostatic analyzer. The source volume was defined on the side nearest the beta detector by a hemispherical bubble of plastic foil, which was about 0.8 mg/cm² thick and was aluminized on its concave surface to

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[13] White, Delsasso, Fox, and Creutz, Phys. Rev. 56, 512 (1939).

make it electrically conducting. The opposite side of the source was defined by the "gate," a flat sheet of aluminum leaf approximately 0.25 mg/cm^2 thick, which was sensibly transparent to the positrons, but of adequate thickness to stop completely the recoil ions. This gate was supported by an aluminum plate which could be rotated by an external handle (F). There were two holes in the movable plate, each 10.5 mm in radius, either of which could be centered in front of the source volume. One hole was covered by the gate and the other was left open. Coincidence counts were observed with the "gate open" and with the "gate closed," and the difference between these two sets of data represented the coincidence rate due to disintegrations within the source.

The geometry of the source region was the same with the gate either open or closed, and the radioactive gas could diffuse freely on both sides of the gate. Positrons from the source volume were recorded by means of a scintillation counter consisting of a hemispherical shell (B) of plastic phosphor cemented into a Lucite light pipe (C), which was in contact with an RCA Type 5819 photomultiplier tube (D). Since the scintillator was made much larger than the source volume, all positrons from the source entered the phosphor at roughly normal incidence, and the detection efficiency was nearly constant for different positions within the source. Recoil ions originating within the source volume were focused into the ion collector electrode (H) by an electrostatic field between the concentric spherical electrodes (G) of the spectrometer. Typical ion trajectories are indicated by the dotted lines in Fig. 1. The spectrometer electrodes were supported and centered by two end plates which also served to cut off the fringing field at the ends of the gap. Since most of the fluorine recoil ions carried one unit of negative charge, the inner electrode was normally positive and the outer one negative. Ions focused into the collector electrode H were accelerated through a potential difference of 2 kv in passing between two conical grids, and impinged on the inner surface of a cylindrical electrode where secondary electrons were released. The structure, consisting of the larger conical grid, two coaxial cylinders, and a flat grid, was so shaped that electrons ejected by ion impact at the inner wall of the first cylinder were focused through the flat grid onto the first dynode of a standard Allen-type[14] electron multiplier (J).

In order to prevent the detection of positrons which could not produce true coincidences, the region between the source volume and the scintillator was sealed off from the main vacuum chamber and evacuated with a separate mechanical pump. The background counting rate of the ion detector was minimized by allowing the radioactive gas to enter the ion detector vacuum can only through the small aperture of the ion collector. The vacuum can enclosing the electron multiplier was evacuated by a separate diffusion pump.

Figure 2 illustrates the main components of the auxiliary apparatus employed in producing Ne^{19} and recording data. Sulfur hexafluoride, previously purified and stored in a metal tank at about 5 lb/in.^{2} above atmospheric pressure, was admitted continuously into the cyclotron target, from which the neon was carried along with the SF_6 through about 40 feet of copper tubing to the main experimental setup. Here the sulfur hexafluoride was frozen solid in a glass trap cooled with liquid nitrogen. Ne^{19} entering the recoil chamber was first purified by passage through a steel trap in which any possible contaminants were removed by chemical reactions with chips of calcium metal heated to 400°C.

Delayed positron-recoil coincidences were recorded by means of an oscilloscope and a camera in which 35-mm film moved continuously at about 1.5 cm per minute. Voltage pulses produced by the arrival of positrons at the electron detector were amplified and then triggered the 1 μsec/cm sweep of the oscilloscope. Recoil fluorine ions entering the ion detector produced pulses which, after amplification and shaping, were applied both to the vertical plates and to the intensity grid of the cathode ray tube. Data were read from the film by counting the number of pulses in each of 24 time channels. When the results were plotted as a histogram, the true coincidences produced by disintegrations in the source region appeared as a well defined peak superimposed on a uniform chance background. The differential energy spectrum of the recoil ions was determined by recording data for several

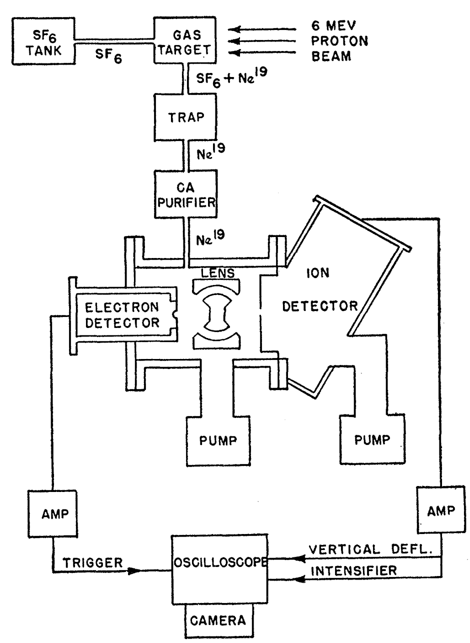

FIG. 2. Simplified schematic diagram of apparatus used in producing Ne^{19} and in recording delayed positron-recoil coincidences.

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spectrometer voltages and counting the total number of true coincidences in each case.

B. Performance of the Spectrometer and Detectors

The electrostatic spectrometer was designed in accordance with the theory due to Purcell[15] and also to Browne *et al.*,[16] the choice of dimensions amounting to a compromise between the conflicting requirements of good detection efficiency *versus* good focusing and energy resolution. The solid angle for the detection of monoenergetic recoil ions from the source center was approximately $0.07\times(4\pi)$ steradians. The performance of the spectrometer was investigated using a source which provided a beam of singly charged argon ions of 210-ev energy. For twelve source positions, corresponding to points within the source volume in the recoil experiment, the observed relation between the ion energy and the total deflecting voltage was in agreement with the calculated value to within 4 percent, and for nine of these positions the agreement was within 2 percent. The measured half-width of the spectrometer resolution curve for a point source was 2.5 percent, as predicted by the first-order focusing theory. The detection efficiency of the spectrometer plus ion detector, as measured with a given flux of ions entering the spectrometer, was found to depend on the location of the source, with a variation of about a factor of three within the source volume. These results, which could not be calculated readily, were included in the computation of the expected recoil energy spectrum.

The ion collector electrode was designed to permit the detection of recoil ions with an efficiency independent of recoil energy. Conical grids were used in order to accelerate the ions along their initial direction of motion and also to cause them to strike the wall of the first cylinder at a location independent of their initial energy. The shapes of the electrodes needed to focus the secondary electrons into the main multiplier structure were determined by plotting trajectories with model electrodes in an electrolytic bath. The performance of the ion collector electrode was investigated with Po alpha particles, and it was found that the detection efficiency increased as the focusing voltage between the cylindrical electrodes was increased up to about 600 v, at which a plateau was reached. Consequently, the highest focusing voltage which gave no evidence of breakdowns, about 750 volts, was used in the recoil experiment. The 2-kv ion accelerating voltage between the conical grids corresponded to about ten times the maximum recoil energy in the Ne^{19} decay. The highest accelerating voltage which could be used was limited by the background counting rate, presumably due to field emission at the first grid, which increased with voltage above about 1 kv. Since most of the investigations[17–19] of secondary emission due to ion bombardment have been carried out using positive ions or neutral atoms, and since no measurements of the detection efficiency *versus* ion energy were made in connection with this experiment, it cannot be stated with certainty that the response of the detector to negative fluorine ions was energy independent. Experimental work has demonstrated,[17] however, that an electron multiplier of this type will count 2-kev Li ions with nearly 100 percent efficiency, and since all of the F ions which could produce true coincidences were (after acceleration) of the same energy to within ± 5 percent, the data were analyzed with the assumption that the ion detection efficiency was independent of the recoil energy.

The positron detection efficiency of the scintillation counter was measured using a 90-degree beta spectrometer with a Na^{22} source. The response was determined as a function of the energy of the positrons for each of several angles ranging from 0 to 75 degrees and measured between the positron beam and the axis of symmetry of the detector (measured at the center of curvature of the phosphor). Most of the measurements with positrons were made in one plane, and the response at other azimuthal angles about the axis of symmetry of the detector was determined by an auxiliary series of observations with a Po^{210} alpha source. The results demonstrated that the detection efficiency dropped off rapidly as the angle between the positron beam and the symmetry axis was increased beyond 40 degrees, and that there was also a pronounced dependence of the efficiency on the azimuthal angle. The first of these effects was to be expected in view of the relatively inefficient collection of light originating far from the center of the scintillator, and the second was found to result from a nonuniform sensitivity of the 5819 photocathode. The positron energy corresponding to a detection efficiency of 50 percent, averaged over six azimuthal positrons, varied from 130 kev at the center to about 920 kev at the extreme edge of the phosphor. These results were used in calculating the expected recoil energy distribution.

C. The Identification of Ne^{19}

A compilation of possible reactions resulting from the proton bombardment of SF_6 indicated that, other than Ne^{19}, no radioactive product with a maximum beta energy between 1.5 and 3 Mev could be formed. In addition, the presence of contaminants with half-lives between 5 seconds and 30 minutes would be unlikely. The Ne^{19} was identified in a preliminary experiment by an energy measurement with aluminum absorbers and a half-life determination using a Brush type BL 202 recorder. The half-life was measured again as a check at the conclusion of the data run. A single activity was

[15] E. M. Purcell, Phys. Rev. **54**, 818 (1938).
[16] Browne, Craig, and Williamson, Rev. Sci. Instr. *22*, 952 (1951).
[17] J. S. Allen, Proc. Inst. Radio Engrs. **38**, 346 (1950).
[18] H. D. Hagstrum, Phys. Rev. **89**, 244 (1953).
[19] J. H. Parker, Jr., Phys. Rev. **93**, 652, 1148 (1954).

observed, with energy and half-life in agreement with the values reported for Ne^{19}.

III. CALCULATION OF THE EXPECTED RECOIL SPECTRUM

In calculating the expected recoil energy distribution, the source volume was divided into five cylindrical and thirteen ring-shaped volume elements and the spectrum was computed for a representative point in each element. Complete calculations were carried out for ten of the eighteen points, and the results for the other points were determined by graphical interpolation. The computed spectra for the different elements were then combined with appropriate weighting factors to obtain the spectrum for the whole source. Since the efficiencies of the detectors and the focusing properties of the spectrometer were included in the computations, the calculated energy distribution could be compared directly with the data.

Schrank and Richardson[11] have investigated the beta spectrum of Ne^{19} and found the maximum kinetic energy of the positrons to be 2.18 ± 0.03 Mev. Willard and Bair[20] have observed the threshold of the $F^{19}(p,n)Ne^{19}$ reaction to be 4.253 ± 0.005 Mev. If one uses atomic masses listed in reference 21 and a neutron-proton rest energy difference[22] of 1.293 Mev, the beta energy calculated from this threshold value is 2.235 Mev. A maximum positron energy of 2.200 Mev was assumed in calculating the recoil spectrum. The neutrino was assumed to have zero rest mass, and the nonrelativistic approximation was used for the kinetic energy of the recoil ion. The Coulomb factor in the beta spectrum was obtained from the tables of Dismuke *et al.*[23] Negligible Fierz interference was assumed. Calculated recoil energy spectra for the case of He^6 decay which illustrate the effect of possible Fierz interference have been given by Rose.[24]

The final result of the computations was an expected recoil energy distribution of the form

$$N(E_R,\lambda)=A[N_0(E_R)+\lambda N_1(E_R)], \qquad (4)$$

where E_R is the recoil energy of ions originating at the center of the source volume and focused into the ion detector. A is a normalizing constant and λ is the constant characterizing the electron-neutrino angular correlation, as given by Eq. (3). $N(E_R,\lambda)$ represents the expected true coincidence rate for a deflecting voltage $V=[(r_2^2-r_1^2)/r_1r_2](E_R/q)=0.576(E_R/q)$ between the spectrometer electrodes, where E_R is the recoil energy in electron volts, q is the number of electronic charges carried by an ion, and r_1, r_2 are the radii of the electrodes. The functions $N_0(E_R)$ and $N_1(E_R)$ were obtained in graphical form. The value of λ (and incidentally the value of A) was found by fitting expression (4) to the data.

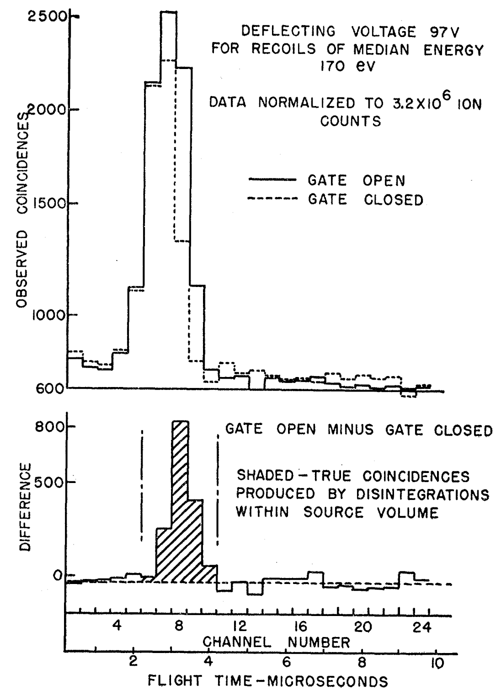

FIG. 3. Time-of-flight distributions of F^{19-} recoil ions with gate open and closed.

IV. RESULTS AND CONCLUSIONS

A. Experimental Results for Negative Recoils

The time of flight distributions corresponding to negative ions observed at a spectrometer voltage of 97v are shown in Fig. 3. At this voltage the detection efficiency should be greatest for ions (from the source center) of 170 ev energy, corresponding to about 85 percent of the maximum possible recoil energy in the decay of Ne^{19}. In the figure are shown the results obtained with the gate open and closed, as well as the difference (open minus closed) which represents the true coincidence count produced by disintegrations within the source volume. The data have been normalized to a total ion count of 3.2×10^6, which is within 5 percent of the numbers actually recorded. Most of the true coincidences with the gate in either position were produced by disintegrations which occurred between the gate and the spectrometer. Recoil ions from this region have shorter flight paths than those originating within the source volume, and consequently the peaks of both directly observed distributions are centered at flight times shorter than that of the difference count. The vertical dotted lines on either side of the peak in the latter distribution represent the limits of the region within which counts were totaled to determine one point of the recoil spectrum. The horizontal

[20] H. B. Willard and J. K. Bair, Phys. Rev. 86, 629 (1952).
[21] Hornyak, Lauritsen, Morrison, and Fowler, Revs. Modern Phys. 22, 291 (1950).
[22] Tollestrup, Fowler, and Lauritsen, Phys. Rev. 78, 372 (1950).
[23] Dismuke, Rose, Perry, and Bell, Oak Ridge National Laboratory Report ORNL-1222, March 7, 1952 (unpublished).
[24] M. E. Rose, Oak Ridge National Laboratory Report ORNL 1593, October 19, 1953.

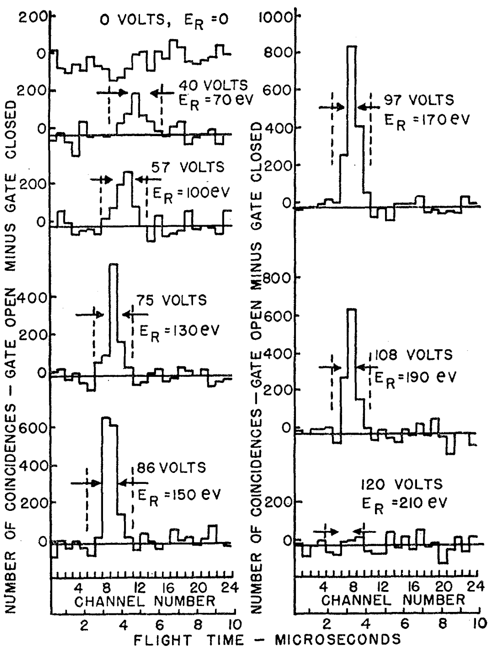

FIG. 4. Time-of-flight distributions of F^{19} ions from source volume.

dotted line indicates the average net chance count per channel computed from the numbers in all channels outside of the vertical lines, and the shaded area under the peak represents the total number of disintegrations which occurred within the source volume.

Time of flight distributions for all of the recoil energies observed are shown in Fig. 4, in which only difference counts are plotted. The polarity of the spectrometer and ion collector voltages permitted the detection of negative ions only. All of the results have been normalized to 3.2×10^6 ion counts. The total ion counts actually recorded were within ±12 percent of this for all cases except at the spectrometer voltages of zero and 120 volts, for which the running time was shorter and the count was only about 1.6×10^6 in each case. Each histogram is labeled according to the spectrometer voltage and the corresponding value of E_R for singly charged ions coming from the source center. The observation of a large peak at 108 volts ($E_R=190$ ev), and the absence of one at 120 volts ($E_R=210$ ev), proved the calculated value of $E_R(\max)=200$ ev to be correct to within ±5 percent. The horizontal arrows in Fig. 4 show the expected location of each peak and the limits of the flight times calculated for ions originating at the source center. These computed time limits correspond to the different flight times of ions moving along trajectories near the inner and outer spherical electrodes. The observed peaks are wider than the limits indicated by the arrows because of the finite source dimensions and the spread in the recoil velocities of ions focused into the ion detector. A small additional broadening, amounting to about 0.2 microsecond, was introduced because the time delay between the incidence of a positron on the scintillator and the start of the oscilloscope sweep was not independent of the size of the triggering pulses. As is evident from Fig. 4, the observed flight times were in good agreement with the expected values. The vertical dotted lines have the same significance as those in Fig. 3, and the horizontal lines indicate the average net background count per channel. The net background, although small in comparison with the heights of the peaks, was consistently negative. This observation can be explained by the assumption that the average specific activity within the source volume was greater with the gate closed than with the gate open. No systematic error in the true coincidence count would result from a concentration of gas behind the closed gate, provided that the specific activity between the gate and the spectrometer were independent of the gate position. In view of the construction of the apparatus as shown in Fig. 1, it seems highly unlikely that the density of gas between the gate and the spectrometer could have been significantly influenced by the gate position, and it is therefore believed that any systematic error which might be inferred by the observation of a negative net background count is small in comparison with the statistical uncertainties. The peaks in the histograms of Fig. 4 were all produced by singly charged negative ions. Recoils of this charge would be expected in Ne^{19} decay, since after the disintegration the fluorine nucleus of charge 9 is left with the ten electrons originally present in the neon atom. Negative ions with two units of charge would not be expected, but it might be mentioned that any appreciable number of such ions would have produced a second peak in the distribution obtained at 40 volts. Such a peak, corresponding to doubly charged ions of 140-ev energy, would be centered at a flight time of about 3.5 microseconds, or 1.4 microseconds earlier than that for the singly charged ions of 70-ev energy detected at the same voltage. There is no indication of any such peak in Fig. 4.

The observed recoil energy spectrum and also the expected distributions calculated for various possible

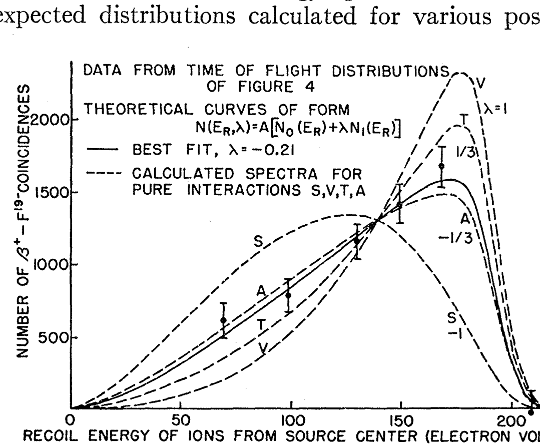

FIG. 5. Energy spectrum of recoil ions from Ne^{19} β^+ decay.

electron-neutrino angular correlations are shown in Fig. 5. Each experimental point in this figure was obtained from the total true coincidence count in the peak of the corresponding histogram in Fig. 4. The "theoretical" spectrum in best agreement with the experimental results was determined by fitting the calculated distribution (4) to the data by the method of least squares, with the result

$$\lambda = -0.21 \pm 0.08,$$

where the indicated uncertainties are standard deviations. There are believed to have been no systematic errors of magnitude comparable to the statistical uncertainties, and no allowance for such errors has been made in the limits stated above. In addition to the curve corresponding to $\lambda = -0.21$, the calculated spectra given by Eq. (4) for the "pure" interactions S, V, T, A are shown in Fig. 5. Each of these curves has been normalized to the same area as that beneath the plot for $\lambda = -0.21$.

B. Beta-Decay Interaction

According to Eq. (3), the experimental result $\lambda = -0.21$ indicates that the beta-decay interaction contains a scalar component and that the (polar) vector component is small or zero. The interaction is therefore of the form STP. This conclusion is based on (1) the results of the He^6 experiments of Allen and Jentschke[1] and of Rustad and Ruby,[2] (2) the results of this experiment, and (3) the assumption of negligible Fierz interference.[7–9] The result that the interaction is STP is in agreement with the conclusions of Mahmoud and Konopinski[7] and of Peaslee,[25] who have analyzed the shapes of beta spectra observed in allowed and forbidden transitions, and is also consistent with the observations of Alford and Hamilton[26] in their recoil experiment on Ne^{19}.

An expected value of the angular correlation constant λ can be estimated[27] from the observed ft values for Ne^{19} and O^{14}. With $ft = 1970 \pm 100$ sec[28] for Ne^{19} and 3275 ± 75 sec[29] for O^{14}, the expected result is $\lambda = -0.07 \pm 0.02$ if one assumes the Fermi interaction component to be S, or $\lambda = +0.53 \pm 0.01$ if one assumes that component to be V. Although the expected value for the STP combination is not in good agreement with the result obtained in this experiment, the VTP interaction definitely appears to be ruled out.

The form of the interaction and the value of $\lambda = -0.21 \pm 0.08$ having been determined, Eq. (3) may be rewritten to yield the ratio

$$\frac{C_S^2 \left| \int 1 \right|^2}{C_T^2 \left| \int \sigma \right|^2} = \frac{1}{3} \left(\frac{1-3\lambda}{1+\lambda} \right) = 0.69 \pm 0.17. \qquad (5)$$

Unfortunately the value of $|\int \sigma|^2$ for the decay of Ne^{19} is not known with certainty. Peaslee[30] has assumed the nuclear configuration to be $(d_{5/2})^3{}_{1/2}$ and quoted the value $|\int \sigma|^2 = 1.6$. Winther and Kofoed-Hansen[28] have assumed $(s_{1/2})^3{}_{1/2}$, "probably in strong admixture with $d_{5/2}{}^2 s_{1/2}$," and found $|\int \sigma|^2 = 2.59$, in agreement with the value of 2.65 given earlier by Trigg.[31] The theoretical value of $|\int \sigma|^2 = 1.6$, however, agrees with the value of 1.6 obtained by Kofoed-Hansen and Winther from a semiempirical relation between the ft values and matrix elements of other mirror transitions. Substitution of $|\int \sigma|^2 = 2.6$ and $|\int 1|^2 = 1$ in (5) yields $C_S^2/C_T^2 = 1.8 \pm 0.4$, whereas with $|\int \sigma|^2 = 1.6$ the result is $C_S^2/C_T^2 = 1.1 \pm 0.3$, where the limits of error include only the statistical uncertainty in the results of this experiment, and neglect the much larger error associated with the uncertainty in the value of $|\int \sigma|^2$. The value 1.1 ± 0.3 is consistent with the results of Blatt[32] ($0.54_{-0.25}^{+0.5}$), of Konopinski and Langer[33] (1.4 ± 0.7 from H^3 and He^6, $0.8_{-0.3}^{+0.5}$ from O^{14} and He^6), of Gerhart[29] ($0.73_{-0.21}^{+0.16}$), of Bouchez and Nataf[34] (0.99 ± 0.24), and of Kofoed-Hansen and Winther[28] (1.0 ± 0.2). From these results it may be concluded that the nuclear configuration is probably $(d_{5/2})^3{}_{1/2}$ and not $(s_{1/2})^3{}_{1/2}$.[35]

The conclusion STP might be checked by an experimental determination of the electron-neutrino angular correlation in a $J = 0 \rightarrow 0$ transition. With a transition of the type $0 \rightarrow 0$ the expected result would be either $\lambda = 1$ or $\lambda = -1$, and consequently a more certain conclusion might be reached with no greater accuracy than that achieved in the present experiment. Once the interaction type has been definitely established, additional information relative to the magnitudes of the coupling constants might be obtained through further recoil experiments, by measuring the angular correlation in other allowed transitions for which $\Delta J = 0$, $J \neq 0$.

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[35] In a private communication, Peaslee has pointed out that the calculation of $|\int \sigma|^2 = 2.6$ for the $(s_{1/2})^3$ configuration assumes a deformable nuclear core, whereas that leading to $|\int \sigma|^2 = 1.6$ for the $(d_{5/2})^3$ configuration does not. A value of $|\int \sigma|^2 = 3$ for the $(s_{1/2})^3$ configuration, obtained without the assumption of a deformable core, might therefore be more appropriate than 2.6 for a comparison of the two configurations. With $|\int \sigma|^2 = 3$, Eq. (5) would yield a ratio of $C_S^2/C_T^2 = 2.1 \pm 0.5$ in greater disparity with the other results quoted above, thus strengthening the conclusion that the configuration is not $(s_{1/2})^3$.

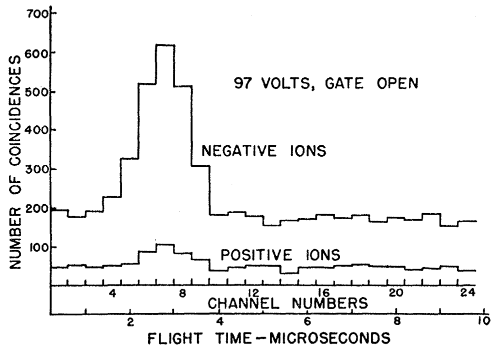

FIG. 6. Time-of-flight distributions of positive and negative F^{19} recoil ions of 170-ev energy.

A^{35} would furnish a good example, and since it is an inert gas it could be handled with apparatus similar to that described above.

C. Positively Charged Recoil Ions

The results of a search for positive recoil ions are shown in Fig. 6, in which time of flight distributions of both positive and negative recoils are plotted. The histogram having the larger peak represents a portion of the data obtained in the observation of the recoil energy spectrum of negative ions, and shows the number of coincidences per channel recorded in about four hours with the gate open. With 97 volts between the spectrometer electrodes, the energy of the ions detected was about 170 ev. The distribution with the smaller peak was observed in about six hours of running time, with experimental conditions which were the same as before, except that the deflecting and accelerating voltages were reversed to permit the detection of positive recoils. The histogram for positive ions has been normalized to the same total positron count as that recorded in the observation of negative ions, so that the two distributions correspond to the same number of disintegrations in the vacuum chamber. The average positron counting rates during the two runs differed by less than 5 percent. The histogram for positive ions shows a definite peak at the same flight time as that observed for negative ions. A comparison of the numbers of counts within the peaks of the two distributions reveals that the true coincidence rate due to positive recoils was about ten percent of that due to negative recoils.

The observed ratio of positive to negative recoils is not amenable to direct comparison with theoretical predictions of the ionization produced in beta decay. Since the absolute disintegration rate was not measured, the relative number of neutral fluorine atoms produced is not known. The relative detection efficiencies for positive and negative ions are also uncertain. According to the calculations of Levinger[36] and of Schwartz,[37] the change of nuclear charge in the decay process should cause the ejection of an electron from either the K or L shells of the daughter atom with a probability of about $2.7/Z^2$ per disintegration, or about 3 percent in this case. A larger ionization probability is predicted if the screening of the nucleus by the electrons is taken into account. The increase amounts to a factor of three for $Z=80$, but would be less for $Z=9$. For the production of positive ions, however, two electrons must have been ejected from the F^- recoils. Serber and Snyder[38] have estimated that the average excitation of the ion, due to the change of nuclear charge, is 54 electron volts for $Z=10$. The ejection of two electrons from an F^- ion requires[39,40] only about 21.5 ev, and is therefore energetically possible. The loss of more than one electron in the K capture of A^{37} has been observed by Perlman and Miskel,[41] who found the average charge of the daughter Cl^{37} ions to be $+3.41\pm0.14$ electron charges. The possibility that the positive ions observed in this experiment might have been produced by scattering seems unlikely, since the work function of the metal surfaces,[42] about 4 ev, is much smaller than the energy required for the removal of two electrons from an F^- ion. Neutralization of negative recoils at a surface was possible, as the electron affinity of fluorine[39] is only 4.1 ev, but neutral particles could not be detected. Although the possibility of scattering cannot be ruled out conclusively, the evidence seems to indicate that the positive ions observed were produced by the ejection of two electrons in the shakeup following the beta-decay process.

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