DETERMINATION OF THE GAMOW-TELLER BETA-DECAY INTERACTION FROM THE DECAY OF HELIUM-6†*

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The electron-neutrino angular correlation coefficient has been measured for the negatron decay of He^6 using the same apparatus[1,2] previously employed to determine the angular correlations in the positron decays of A^{35} and Ne^{19}. He^6 decays with a half-life[3] of 0.85 sec by beta-particle emission to Li^6 with a maximum beta energy[4] of 3.5 Mev and a spin change $\Delta I = 1$ with no change in the nuclear parity.[5] Thus, He^6 obeys only the rules for allowed Gamow-Teller decay and the angular correlation coefficient λ should be either $+\frac{1}{3}$ or $-\frac{1}{3}$ corresponding, respectively, to the tensor or axial-vector interaction. Our experimental result, $\lambda = -0.39 \pm 0.02$, clearly indicates that the axial-vector interaction is dominant.

The He^6 was produced by the reaction $Be^9(n,\alpha)He^6$. The beryllium was in the form of powdered BeO enclosed in a stainless steel tube which was placed in a high flux of fast neutrons in the central core of the research reactor CP-5 at Argonne National Laboratory. Two porous stainless steel filters running lengthwise down the tube allowed a carrier gas to pass directly through the BeO. Sulfur hexafluoride was used as the carrier gas because it could be frozen out easily by liquid nitrogen traps and then recirculated. The active gas was carried for a distance of about 40 feet through $\frac{3}{8}$-inch copper tubing from the top of the reactor to the basement. The He^6 gas was then separated from the carrier gas in the nitrogen traps and entered the source volume of the spectrometer through a furnace in which chips of calcium metal were heated to about 500°C. The calcium trap was expected to remove any chemically active radioactive elements which could have passed through the tubing, filters and nitrogen traps. The most likely contaminant was N^{16}, since this possibly could pass through the calcium trap. This activity decays by negatron emission with a half-life of 7.4 sec and can be formed by the reaction $O^{16}(n,p)N^{16}$. Half-life measurements were made using a plastic scintillator placed in the source volume. A fast-acting valve, mounted between the source volume and the calcium trap, was used to seal off the source volume for the half-life measurements without affecting the flow of activity from the reactor. This system had the advantage that it avoided changing the background at the scintillator during the period in which half-life measurements are actually being made. The results of the measurements indicated a single activity with a half-life of 0.83 ± 0.02 sec, in good agreement with the value 0.85 ± 0.03 sec given by Rustad and Ruby.[3] When the temperature of the calcium trap was lowered, an impurity of several percent was observed which appeared to be N^{16}. When the trap was operated at the higher temperature, it was estimated that the activity of this impurity was less than 1% of the He^6 activity. An unsuccessful attempt was made to use finely powdered beryllium metal as a source of He^6, with either propane or sulfur hexafluoride as a carrier gas. The propane decomposed very readily under neutron bombardment and the sulfur hexafluoride reacted explosively with the beryllium metal. Powdered BeO proved to be highly satisfactory, however, with SF_6 as the carrier gas, and the source was able to produce more He^6 than was actually used in the angular correlation measurements.

The shape of the energy spectrum of ions recoiling from the beta-decay of a nucleus depends on the angular correlation between the directions of emission of the beta-particle and the neutrino. Thus, in this experiment λ was determined by making a simple measurement of this spectrum in a suitable spectrometer without the complication of detecting the coincident beta-particle. However, the strength of the He^6 beta-activity in the source volume was monitored by the same scintillator as was used to determine the half-life. The pressure in the source volume was kept below 10^{-4} mm Hg so that the mean free path for the ions was long compared to the distance they had to travel through the source volume. The pressure in the rest of the system was less than 5×10^{-6} mm Hg.

The spectrometer consisted of two spherical electrostatic energy analyzers in series. A conventional Allen-type electron multiplier was used as the ion detector. A cylindrical dynode in the first stage of the ion detector was mounted in a special grid system which allowed an accel-

erating potential to be applied to the recoil ions just before they struck the first dynode. This potential was adjusted whenever the energy setting of the spectrometer was changed so that all recoil ions had an energy of 4400 ev when they hit the cylindrical dynode. The detection efficiency was tested with a lithium ion source and was found to be constant within instrumental error over the entire range of recoil energies.

The ratio of the true effect to the background with this apparatus appears to be about 10% at maximum. Most of the background was caused by He^6 gas which drifted through the spectrometer system into the ion detector before decaying. A differential pumping system based on small apertures in the three focal planes of the spectrometers reduced the background to the level given above. This background was measured by making half of each run with a repelling potential applied to a grid over the aperture from the source volume. The repelling potential was maintained at a sufficiently high level to stop all recoil ions from the beta-decay of He^6.

The experimental points for He^6 and the theoretically predicted spectra for various values of the angular correlation coefficient λ are shown in Fig. 1. The theoretical curves have been corrected for the Coulomb effect and for the finite resolution of the spectrometer system. The experimental point on the steep right side of the spectrum was used to locate the experimental energy scale relative to the theoretically predicted maximum recoil energy. The rest of the points between 700 and 1400 ev were used in a least-squares analysis to determine a value of $\lambda = -0.39 \pm 0.02$. Each of the points used for the determination of λ had about 10^5 true recoil counts, and an error of about 2000 counts.

The points below 700 ev were not used in the least-squares analysis for two reasons. Firstly, as is readily seen in Fig. 1, the curves are not very sensitive to the value of λ below this energy. Secondly, approximately 10% of the recoil ions are multiply charged,[6] and since the spectrometers transmit a doubly charged ion of 1400 ev at the same energy setting as a singly charged ion of 700 ev this has the effect of increasing the number of counts at all energies below 700 ev by an amount which is not accurately known. The three points which are shown below 700 ev demonstrate the effect produced by multiply charged recoil ions.

At present, it is not known why our result differs from the expected value of -0.33 by more than the statistical error. Either the linearity

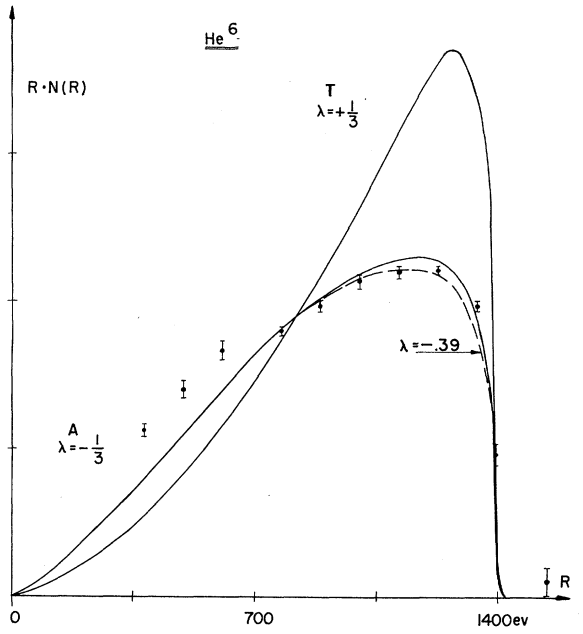

FIG. 1. The distribution of recoil ions observed in the decay of He^6 plotted as a function of the recoil energy R. The solid curves are the computed distributions for the tensor (T) and axial vector (A) interactions. Since the transmission of the spectrometer is proportional to the recoil energy, the probability function $N(R)$ is shown multiplied by R. The dotted curve represents the best fit with the data. The experimental points below 700 ev include the multiply charged ions.

of response of the spectrometer-detector system or the presence of small amounts of an undetected impurity could be responsible. It has also been suggested that the phenomenon of producing multiply charged recoil ions may not be entirely energy independent. These possibilities are being investigated at the present time but they do not appear to offer any solution which could be checked in the immediate future.

Figure 2 is a composite of the results of the experiments on A^{35}, Ne^{19}, and He^6. The curves represent the best fits with the data for each of the three beta decays with the vertical normalization corresponding approximately to equal activities in each case. Since these measurements were all made with the same apparatus it is very satisfying that the results are consistent with each other although the shapes of the experimental curves vary from one which is sharply peaked at high recoil energies to one which is rather flat.

The measurements strongly support an axial vector-vector interaction for nuclear beta-decay,

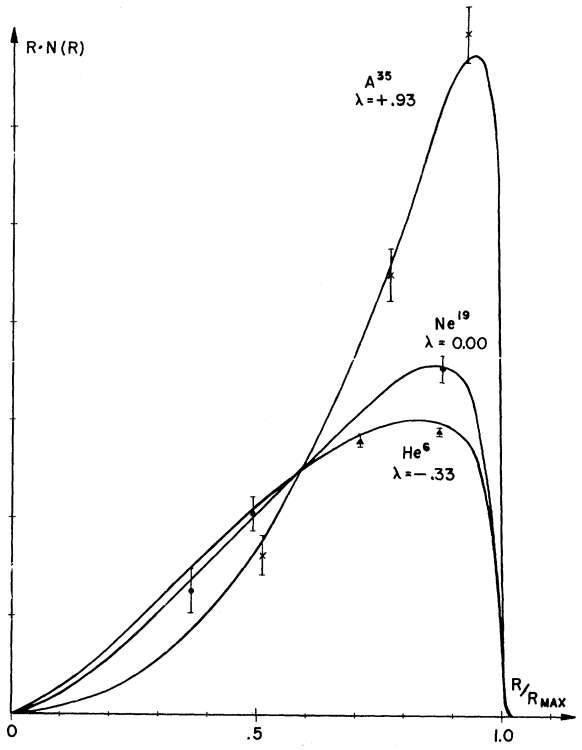

FIG. 2. The results of the A^{35}, Ne^{19}, and He^{6} experiments together with the theoretically predicted recoil energy spectra. The points shown are a representative sample of the data actually used for the calculation of the results.

in agreement with other recent results[7,8] in quite different types of experiment.

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EXPERIMENTAL OBSERVATION OF DOUBLE COULOMB EXCITATION*

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In regions of the periodic table where nuclei have large spheroidal deformations, it is well known that there are, associated with the ground states of even-even nuclei, rotational bands in which the members have spins and parities of 0+ (ground), 2+, 4+, 6+, etc.[1] The 4+ state belonging to this rotational band can be Coulomb excited either by a direct $E4$ excitation or by a double $E2$ process via the 2+ member of the band.[2] (Other intermediate states can also give a contribution, but that from the 2+ state is likely to predominate.) When heavy ions are used as bombarding particles, the probability for the double $E2$ process is expected to become high, and to exceed considerably that for the $E4$ excitation.

In order to observe double $E2$ Coulomb excitation, we bombarded thick targets of natural tungsten with oxygen ions from the Berkeley heavy-ion linear accelerator. Natural tungsten consists almost entirely of three even-even isotopes W^{182}, W^{184}, and W^{186}, and of the odd-mass isotope W^{183} in 14% abundance. These nuclei are known to be highly deformed and to have rotational bands. The gamma rays arising from the decay of the excited states were observed with 1 in. × $1\frac{1}{2}$ in. diameter NaI (Tl) crystals together with a 50-channel and a single-channel pulse-height analyzer.

The pulse-height spectrum showed two broad peaks, having mean energies of 114 and 250 kev. The lower energy peak arises almost completely from the decay of the known first excited states of W^{182}, W^{184}, and W^{186}, which have energies of 100.07 kev, 111.13 kev, and 122.48 kev, respectively.[3] We believe that the second broad peak arises from the decay of the 4+ to the 2+ states of the even-even nuclei, and from the decay of