A Re-Investigation of the Double Beta-Decay from Sn^{124}

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(Received February 5, 1952)

Radiations from natural tin and tin enriched with the 124 isotope are examined in a magnetic field with a helium filled cloud chamber that is triggered by internal counters. Only three pictures out of more than four thousand photographs are pictures of two electrons coming out of the same point in the tin and entering the counters, and even these may be pictures of multiply scattered electrons passing through the tin. However, one may set a lower limit to the half-life of double beta-decay from Sn^{124} as 10^{17} years. This is a decay rate less than one-tenth of a value previously reported by one of the authors.

INTRODUCTION

THEORIES of the neutrino predict different properties for the double beta-decay process. Some[1] predict that two neutrinos accompany the two electrons. Others[2–5] require no neutrinos. Therefore, the deciding point between the two types of theories is the sum of the energies of the two electrons. This sum is either constant and equal to the mass difference or has a distribution of values. The two types of theories also predict different half-lives for the process; however, the fourth power of the nuclear matrix element enters into the half-life calculation. This matrix element must be less than one; otherwise its magnitude is quite uncertain. Therefore, a measurement of a minimum half-life for the process is not a conclusive way of distinguishing between the theories.

Attempts[6–9] have been made to detect double beta-decay from various isotopes. In the main these have given negative results, i.e., minimum half-lives for the process. In a previous letter one of the authors[6] had interpreted a slight coincidence activity from a Sn^{124} sample as a possible double beta-activity. It was therefore decided to re-investigate Sn^{124} with the present apparatus, which is more sensitive for detecting rare coincidence electrons than the previous apparatus. The present apparatus also measures the energies of the electrons.

DESCRIPTION OF APPARATUS[10]

A cylindrical cloud chamber of $12\frac{1}{8}$-in. inside diameter and $4\frac{5}{8}$-in. depth is filled with helium and ethyl alcohol at 108-cm pressure at 20°C temperature. The tin sample is placed across the center of the chamber. This sample acts both as a source and as the chamber clearing field. Three different samples were used in the experiment: a sheet of tin of normal isotopic constitution $10\frac{1}{2}$ in. long, 4 in. high, and 0.003 in. thick; another sheet of the same tin rolled to 0.0008-in. thickness; and a tin sample enriched in the 124 isotopes of 2.2205-g weight, and 0.0015-in. thickness. The enriched sample was obtained from Oak Ridge[11] and contained the 124 isotope in 95.04 percent abundance.

On either side of the sample is a counter. Initially open counters, whose interior form part of the visible region of the cloud chamber, were used. Later thin-walled counters (30 mg/cm^2) were used. The open counters require more care than the thin-walled ones; therefore, most of the data have been taken with the thin-walled counters. The chamber is triggered by coincidence pulses from the two counters (1 microsecond resolving time). The open counters are $10\frac{1}{2}$ in. long. The thin-walled counters consists of a bank of three counters in parallel (each $\frac{3}{4}$ in. in diameter and 6 in. long). These counters subtend a solid angle between one and two steradians at the source. The single counting rate in each set of thin-walled counters is 80–90 counts/min; in the open counters it is about 500 counts/min.

The cloud chamber is placed in a horizontal position to reduce the number of cosmic rays. Nevertheless, a large percentage of the pictures are horizontal cosmic-ray mesons and showers. Rather than eliminate these events by anticoincidence counters, it was decided to keep these as an interesting sideline.

Helmholtz coils about the chamber give a magnetic field uniform to 1 percent over the chamber volume. The magnetic field is on continuously. Magnetic fields up to 900 gauss were used. However, most pictures were taken with the field in the neighborhood of 200 gauss. A larger magnetic field cannot be profitably used since low energy electrons would then curl up before reaching the counters. The coincidence rate is dependent upon the magnetic field strength. At zero field strength, there is one coincidence per minute; at 185 gauss there is one

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[2] W. H. Furry, Phys. Rev. **56**, 1184 (1939).
[3] B. Touschek, Z. Physik. **125**, 108 (1948).
[4] A careful analysis of neutrino theories and their effects on the double beta-process is given by Jayme Tiomono in a Princeton thesis (1950).
[5] L. A. Sliv, Zhur. Eksp. Teoret. Fiz. S.S.S.R. **20**, 11, 1039 (1950).
[6] E. L. Fireman, Phys. Rev. **74**, 1238 (1948); **75**, 323 (1949).
[7] M. G. Inghram and J. H. Reynolds, Phys. Rev. **76**, 1265 (1949); **78**, 822 (1950).
[8] Levine, Ghiorso, and Seaborg, Phys. Rev. **77**, 296 (1950).
[9] Marvin I. Kalkstein, University of Chicago thesis (1951).
[10] The apparatus is similar in some respects to one described by E. L. Fireman and G. M. McHaney, Rev. Sci. Instr. **21**, 813 (1950).
[11] The authors wish to thank Y-12 Branch of the Oak Ridge Stable Isotope Division for a four-week loan of this specimen. Presumably, this is the same specimen used by Kalkstein in his experiment.

TABLE I. Tin of normal isotopic constitution (0.003-in. thickness).

Magnetic field (gauss)	Mesons	Electrons	Scattered electrons	Showers	Double electrons	Coincidence pictures taken
350	3	3	6	3	none	26
390	27	18	17	25	none	272
450	24	21	14	23	none	267

coincidence every two and one-half minutes; and at 900 gauss there is one coincidence every three minutes. This dependence is caused mainly by the bending of low energy electrons from the chamber walls.

The sensitive time of the chamber is less than 0.1 second. Therefore at 185-gauss field strength the triggered picture is equivalent to more than 1500 random ones.

For accurate energy measurements, the magnetic curvature should be large compared to the multiple scattering curvature. According to Bethe's formula,[12] the multiple scattering from our chamber gas with our average track length corresponds to a field of $H_s=31/\beta$ gauss, where β is the ratio of the velocity of the electron to the velocity of light. For 340-kev electrons β is 0.8 and H_s is 39 gauss. It is interesting to note that the ethyl alcohol vapor makes a larger contribution to the multiple scattering than the helium.

A mirror gives a stereoscopic view in addition to the direct view of the chamber. The photographs are reprojected through an optical system identical to the one used in taking the pictures.

RESULTS

Coincidence tracks are classified in the following manner; if they are straight, they are called mesons. If they are bent in the form of a "C," they are called electrons. If they are scattered in the source giving the form "3," they are called scattered electrons; these could also be electron-positron pairs arising in the source. If the picture contains more than four tracks with at least one passing through both counters, it is called a shower. And finally, if the track has an "S" shape with the sign of curvature correct for electrons leaving the source, it is called a double electron track.

Tracks of the "S" type could be due to the double beta-process or to a beta-internal conversion electron of some contaminant.[13] Multiple scattering from the gas could also give a double electron track by changing the sign of the curvature of an electron passing through the source on the side which it approaches the source.

If sufficient "S" type tracks are observed, the double beta-process could be distinguished from a beta-internal conversion process by the energies of the electrons. In the beta-internal conversion process, one of the electrons has a constant energy. This is not true of the double beta-process either with or without neutrinos.

The data are summarized according to the above classification in Tables I, II, and III.

Only three pictures are those of double electrons coming out of the same point in the source and entering the counters. The curvatures and energies of these tracks are given in Table IV.

In addition to these three, there are two photographs of the "S" form whose curvatures (18.8 cm, 16.8 cm) and (12.8 cm and 14.2 cm) have the wrong sign for electrons leaving the source. These pictures can only be interpreted as an electron passing through the source and having the sign of its curvature on the side where it leaves the source changed by gas scattering. This leads us to the belief that some of the three double electron pictures are probably multiply scattered electrons with the wrong sign of curvature rather than double beta-electrons from tin 124. It should also be noted that the sum of the energies of the electrons given in Table IV is not constant. All of the coincidence tracks except a few of the meson tracks have close to minimum ionization. In several of the shower pictures there are a number of alpha-tracks.

If the three photographs are interpreted as double

TABLE II. Tin of normal isotopic constitution (0.0008-in. thickness).

Magnetic field (gauss)	Mesons	Electrons	Scattered electrons	Showers	Double electrons	Coincidence pictures taken
0	35	3	28	23	none	424
420	45	43	42	84	none	633

TABLE III. Tin enriched with 124 isotope to 95.04 percent abundance (0.0016-in. thickness).

Magnetic field (gauss)	Mesons	Electrons	Scattered electrons	Showers	Double electrons	Coincidence pictures taken
0	1	3	4	none	none	16
80	2	none	1	none	none	6
160	6	7	9	5	none	38
185	156	257	183	171	3	1904
310	39	59	29	58	none	520
400	5	15	4	14	none	100
860	3	2	1	4	none	70

TABLE IV. Curvatures and energies of two electrons out of tin.

Magnetic curvature (cm)	Electron energies (kilovolt)	Sum of energies (kilovolts)
10.2	255	750
15.8	495	
11.0	290	785
15.8	495	
8.8	195	330
7.0	135	

[12] H. A. Bethe, Phys. Rev. 70, 822 (1946).

[13] The tin samples were examined spectroscopically for impurities; no impurities of significance were found.

beta-events, a half-life of $2-5\times10^{17}$ years is obtained for the process. A result of three pictures in a field of 175 gauss when the multiple scattering corresponds to a field of 39 gauss is certainly a negative result, and the experiment should be interpreted as giving a half-life greater than 10^{17} years for the double beta-decay process. It was thought worthwhile to report these results, since they differ significantly from those reported in reference 6 and agree with those in reference 9.

The previous result[6] may have been caused by a small trace of an impurity having a coincidence activity in the enriched sample. In fact, some of the three double electron pictures in this experiment may have the same origin.

The authors wish to thank E. Bolze and B. R. Gibbs for aid in designing the apparatus and Anthony Del Duca who designed and constructed the electronics equipment.

PHYSICAL REVIEW VOLUME 86, NUMBER 4 MAY 15, 1952

The Association of Bursts and Penetrating Showers*

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(Received July 19, 1951)

Local cosmic-ray bursts and penetrating showers have been studied together using an arrangement of ionization chambers and shielded counters. The experiment investigated (1) the occurrence of penetrating showers associated with large bursts, and (2) the occurrence of bursts associated with large penetrating showers. Evidence is presented to show that the bursts are mainly locally generated large electronic cascades. Nearly 60 percent of bursts larger than 25 Bev (about 250 electrons) contained observed penetrating component. The transition effect of penetrating and nonpenetrating bursts was in qualitative agreement with a nuclear cascade process. Bursts of a few hundred electrons contained on the average about 1 percent of penetrating particles. Essentially no penetrating showers of multiplicity over 14 were unaccompanied by fairly large electronic cascades. The consistent association of cascade bursts with penetrating showers and vice versa is in qualitative agreement with present neutral meson concepts. The main experimental work was done at Echo Lake, Colorado (elev. 3260 m).

I. INTRODUCTION

THE existence of the electronic component of mixed showers has been of considerable interest in the study of high energy interactions. Recent cloud-chamber experiments[1-8] have established roughly the nature of the phenomenon.

The question of the extent to which the electronic component is associated with the penetrating component, and vice versa, has been incompletely answered. Results obtained with an ionization chamber used in conjunction with a cloud chamber indicate that penetrating particles are frequently produced in those nuclear interactions which give rise to electron showers.[3] British ion-chamber and counter experiments[9] also have found a penetrating component associated with burst production. On the other hand, nuclear interactions have been observed which contained electronic cascades alone, or which have shown a penetrating component associated with no visible electronic cascades.[8]

It was the purpose of the present experiment to study the correlation of electron cascade and penetrating shower production in local nuclear interactions of high energy and multiplicity. We have used the M.I.T. ionization chamber burst method[3,10-12] to detect the cascade radiation produced in the interactions under study. The penetrating component was required to discharge counters under thick lead. A lead shield was disposed above the apparatus to serve as a generator of mixed showers.

The data were obtained at Echo Lake, Colorado, at an elevation of 3260 meters. A light wood building having a roof 2.5 g/cm² thick and walls 1.5 g/cm² thick housed all equipment.

The notation and units used in this paper are those of Rossi and Greisen,[13] while the terminology follows that of the M.I.T. group.[3,14]

* Most of the material presented is from the Cornell University Ph.D. thesis (1950). Preliminary results have been reported in *Proceedings of the Echo Lake Cosmic Ray Symposium* (1949).

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