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Disintegration of Positive and Negative Mesotrons in Different Absorbers

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The β-decay of positive and negative mesotrons has been studied in the case of boron, carbon, aluminum, and iron absorbers. Positive mesotrons showed a decay process in all of the above four absorbers, while negative mesotrons indicated decay phenomena (having mean lifetimes greater than about 0.6 microsecond) in only the boron and carbon absorbers. Results are in agreement with other similar experiments of this type, showing that for negative mesotrons decay phenomena predominate in absorbers of small atomic number and capture processes are more probable in absorbers of large atomic number.

I. INTRODUCTION

SEVERAL investigators[1] have found a ratio of approximately 0.5 between the number of disintegration electrons and the number of mesotrons of both signs stopped in absorbers of moderately high atomic number ($Z \geqq 13$). A recent similar investigation[2] using an absorber of low atomic number ($Z=4$) showed a value of about one for the above ratio. A more detailed experiment by Conversi, Pancini, and Piccioni[3] investigated the decay of positive and negative mesotrons separately in carbon and iron absorbers and showed that negative mesotrons emitted decay electrons when absorbed in carbon but not when absorbed in iron. The interpretation of these results was that the capture probability of negative mesotrons by nuclei increased with increasing atomic number while positive mesotrons underwent the same decay process in all absorbers. A recent determination[4] of the lifetime of mesotrons of both signs in aluminum ($Z=13$) gives an indication that negative mesotrons undergo a measurable decay process in this element.The investigation described in this paper is similar to the experiment carried out by Conversi and others[3] except in that two additional absorbers were investigated, and a somewhat different experimental arrangement was used.

II. EXPERIMENTAL ARRANGEMENT

The experimental arrangement shown in Fig. 1 was used to study the relative number of disintegration electrons arising from positive and negative mesotrons stopped in different absorbers. The method used to separate the positive and negative mesotrons consisted of using a large piece of magnetized iron to force incoming particles of opposite sign into two well separated directions. The absorber under investigation received two beams of singly charged mesotrons and was surrounded by twelve decay electron counters.

The Geiger-Müller counter tubes used in this experiment were of the all-metal (brass) construction type[5] and were filled with the standard 10 percent ethyl alcohol and argon mixture to a total pressure of 10 cm of mercury. The counters had a central wire of 5 mils, an outside diameter of 2 inches, and a length of 23 inches, with the exception of counters E and X, which had lengths of 27 inches and 36 inches, respectively. The experiment was set up in the basement of a concrete building located at an altitude of 5000 feet and was run continuously over a period of six months.

The four absorbers were alternated every two or three weeks to minimize and average out errors resulting from any slow time changes occurring in the electronic equipment, Geiger-Müller counters, or cosmic-ray intensity. The direction of the magnetic field, which permitted the study of either positive or negative particles, was reversed approximately every 24 hours.

The magnetized iron was arranged in the form

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[1] F. Rosetti, Phys. Rev. 60, 198 (1941); B. Rossi and N. Nereson, Phys. Rev. 62, 417 (1942); M. Conversi and O. Piccioni, Nuovo Cimento 2, 71 (1944); Phys. Rev. 70, 859 (1946).

[2] T. Sigurgeirsson and A. Yamakawa, Phys. Rev. 71, 319 (1947).

[3] M. Conversi, E. Pancini, and O. Piccioni, Phys. Rev. 71, 209 (1947).

[4] H. Ticho, Phys. Rev. 72, 255 (1947).

[5] V. H. Regener, Rev. Sci. Inst. 18, 267 (1947).

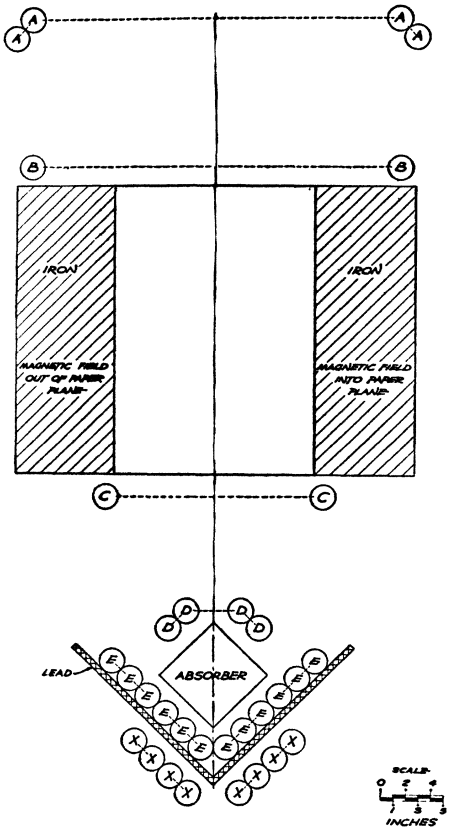

FIG. 1. Experimental arrangement used to investigate decay phenomena of positive and negative mesotrons in different absorbers.

of a square loop, having a width of 8 inches and a height of 24 inches. A coil winding of 4250 ampere turns on two legs of this loop provided an average magnetic induction of 10,000 gauss inside the iron. Counters A and B defined two beams of particles entering the iron piece. Counters C and D defined two beams of mesotrons of the same sign emerging from the iron. The diagram shows the magnetic field so that predominantly negative mesotrons are incident on the absorber.

After plotting the path of mesotrons passing through the magnetized iron, the counters A, B, C, and D were placed along this path so that mesotrons emerging from the iron would have a low momentum value ($p \cong 10^8$ ev/c) and be stopped in the absorber. The path of the mesotrons was determined by a step by step method, taking the energy loss resulting from ionization inside the iron into account. Mesotrons emerging with the above momentum would have to enter the iron piece with a momentum of about 9×10^8 ev/c. If mesotrons entered with momentum values considerably less than 9×10^8 ev/c, they would be stopped in the iron, while mesotrons entering with momentum values considerably greater would miss counters D. The permissible entering mesotron momentum range for the counter path $ABCD$ was estimated to be between 8×10^8 ev/c and 10.5×10^8 ev/c. Mesotrons possessing the upper momentum limit would not be stopped in the absorber, even when using iron as an absorbing material.

Dotted lines between counters indicate a parallel connection. Connecting more than four counters together was avoided because of the slow rise time of the signals arising from such a combination. An electronic mixing system was provided for multiple inputs coming from a set of counters being used for the same purpose. The four counter sets A, B, C, and D were connected into a coincidence unit, and the counters X were connected in anticoincidence with the fourfold coincidence set. The counters E surrounding the absorber were used to detect decay electrons arising from mesotrons stopped in the absorber. A coincidence $ABCD$ usually indicated the passage of a mesotron of one sign through the magnetized iron and into the absorber. An anticoincidence $ABCD-X$ usually indicated that the mesotron had either stopped in the absorber or in the one-half inch lead layer located between E and X. The anticoincidence system was not completely effective in that the X counters did not entirely cover the solid angle subtended by the fourfold coincidence set and in that particles could pass between the X counters. The one-half inch lead layer was placed between the absorber and the X counters to prevent decay electrons from discharging the X counters and thereby nullifying a mesotron anticoincidence $ABCD-X$.

Absorber materials used in the experiment had the following weights and dimensions:

Absorber	*Dimensions*	*Weight*
Boron surrounded by iron container weighing 3600 g	4½″×6″×18″	10,700 g (boron)
Carbon	6″×6″×36″	42,500 g
Aluminum	6″×6″×30″	47,700 g
Iron	Six pieces (¼″×6″×36″) occupying a space of 6″×6″×36″	41,500 g

III. ELECTRONIC UNITS

A block diagram of the electronic units used in this experiment is shown in Fig. 2. A standard coincidence and anticoincidence unit having a resolving time of 1.5 microseconds was used to furnish signals to drive mechanical registers recording these two events. A coincidence *CD* was used to provide a time signal when the mesotron entered the absorber material. This signal was delayed by about 3 microseconds by a delay line and then made square for a duration of 10 microseconds by a multivibrator before going to one input of a triple coincidence unit. The anticoincidence signal was introduced into a second input of the triple coincidence unit after having been made square for 20 microseconds with a multivibrator. The decay electron pulse from the *E* counters was fed into a third input of the coincidence unit after first having been made square for 20 microseconds and then converted with a blocking oscillator into a signal having a fast rise time and a decay time of about one microsecond.

The purpose of first making the decay electron signal square was to eliminate decay electron counts arising from mesotrons stopped in the lead layer. Thus, a mesotron stopping in this lead layer would almost invariably pass through one of the *E* counters. This would trigger the 20-microsecond multivibrator connected to the *E* counters and make it impossible for any subsequent decay electron pulses occurring in the next 20 microseconds from the *E* counters to be transmitted to the triple coincidence unit. The 20-microsecond square signal produced when any of the *E* counters were discharged also eliminated decay electron counts arising from mesotrons being absorbed in the lower half of the walls of the *E* counters.

The register attached to the triple coincidence unit recorded signals from the *E* counters when they were delayed against a *CD* coincidence in the range from 2.3 to 12.5 microseconds. Furthermore, such signals could be recorded only when an anticoincidence, $ABCD-X$, occurred. Because of natural time lags in the *C* and *D* counters, the *CD* coincidence signal lagged the passage of the mesotron on the average by about 0.3 or 0.4 microsecond. This meant that a decay electron could not be recorded until about 2.6 microseconds, on the average, had elapsed from the passage of the mesotron. The 10-microsecond multivibrator in the *CD* coincidence line determined the time interval in which decay electron pulses could be recorded. The multivibrator in the anticoincidence line was made twice as long as to insure coverage of the *CD* coincidence multivibrator signal.

The purpose of permitting delayed counts from counters *E* to begin recording at the rather large time lag of 2.3 microseconds after the *CD* coincidence was to make very certain that natural time lags from the *E* counters would not enter into the observed delayed count. An additional channel, not shown in Fig. 2, was made to record decay electrons which were delayed within the interval 1.2 to 12.5 microseconds. Natural time lags from the *E* counters were noticed in this interval, and therefore data from this channel are not included in this report. The delay time setting of 2.3 microseconds also aided in giving the anticoincidence signal ample time to reach the triple coincidence unit ahead of the *CD* coincidence signal. Serious disadvantages of this large time delay were to considerably reduce the decay electron counting rate, and to obscure the observation of decay phenomena occurring with

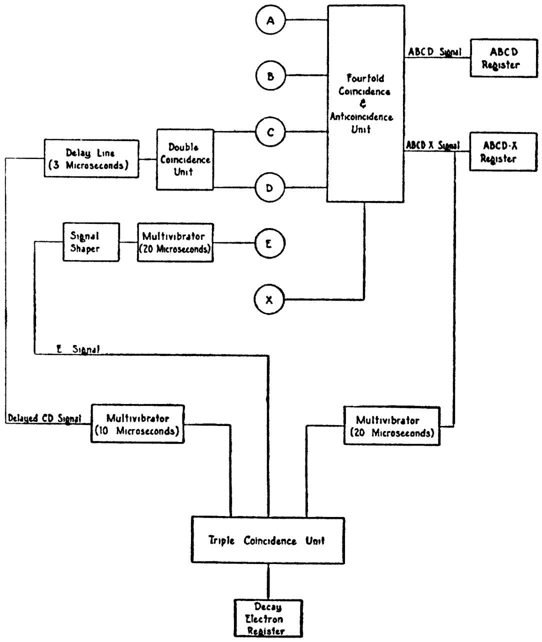

FIG. 2. Block diagram of electronic units connected to experimental arrangement shown in Fig. 1.

TABLE I. Experimental results.

Absorber material	Mesotron sign	Coincidences (*ABCD*) per hour	Ratio of positive to negaive coincidence rate	Anticoincidences (*ABCD–X*) per hour	Ratio positive to negative anticoincidence rate	Total running time for delayed counts	Total delayed counts	Delayed counts per hour	Delayed counting rate corrected for positive mesotron excess
Boron (in iron continer)	Positive	46.7 ±0.4	1.10 ±0.01	18.5 ±0.2(5)	1.19 ±0.02	380 hrs.	66	0.17 ±0.02	0.14 ±0.02
	Negative	42.5 ±0.4		15.5 ±0.2(5)		350 hrs.	27	0.08 ±0.01(5)	0.11 ±0.01(5)*
Carbon	Positive	47.5 ±0.4	1.10 ±0.01	19.0 ±0.2(5)	1.16 ±0.02	310 hrs.	53	0.17 ±0.02(5)	0.14(5) ±0.02(5)
	Negative	42.6 ±0.4		16.4 ±0.2(5)		295 hrs.	32	0.11 ±0.02	0.11 ±0.02
	Both signs (no magnetic field)	30.7 ±0.7		10.7 ±0.4		65 hrs.	4	0.06 ±0.03	
Aluminum	Positive	45.2 ±0.4	1.10 ±0.01	20.1 ±0.3	1.17 ±0.03	320 hrs.	64	0.20 ±0.02(5)	0.17 ±0.02(5)
	Negative	41.0 ±0.4		17.2 ±0.3		265 hrs.	6	0.02 ±0.01	0.02 ±0.01
Iron	Positive	47.6 ±0.5	1.09 ±0.02	19.7 ±0.3	1.18 ±0.03	150 hrs.	27	0.18 ±0.03(5)	0.15 ±0.03(5)
	Negative	43.5 ±0.5		16.7 ±0.3		150 hrs.	3	0.02 ±0.01	0.02 ±0.01
	Both signs (no magnetic field)	31.0 ±0.8		11.5 ±0.5		50 hrs.	2	0.04 ±0.03	
None	Positive	47.0 ±0.4	1.11 ±0.01	16.7 ±0.3	1.18 ±0.03	260 hrs.	8	0.03 ±0.01	0.02(5) ±0.01
	Negative	42.5 ±0.4		14.2 ±0.3		240 hrs.	6	0.02(5) ±0.01	0.02(5) ±0.01

* This value is corrected for effect of iron container surrounding boron absorber (see text).

very short periods. Decay processes having mean lifetimes of approximately 0.6 microsecond or less would not be detected in the present experiment.

IV. RESULTS AND DISCUSSION

Results obtained from the experiment are tabulated in Table I. In all cases the standard error is given.

The coincidence rates indicate a positive mesotron excess between 9 and 11 percent, while the anticoincidence rates show a positive mesotron excess between 16 and 19 percent. The anticoincidence figures have been chosen for positive-excess corrections applied to the delayed counting rate since they indicate the excess of positive mesotrons stopped in the absorber producing the decay electrons (and in the $\frac{1}{2}$-inch lead layer). As will be shown later, the result obtained from the anticoincidence rates is less affected by scattering phenomena; furthermore, it agrees better with positive-excess results obtained by other investigators.[6]

The anticoincidence rate does not change greatly from that when no absorber is present to that when an absorber is inserted. This shows that the majority of the anticoincidences are due to mesotrons stopped in the lead absorber and also to the inefficiency of the anticoincidence arrangement. However, the corrected decay electron counting rate from positive mesotrons increases over the background rate by factors between 6 and 7 when an absorber is inserted. Therefore practically all of the observed delayed counts arise from decay processes in the absorber material.

The background effect was taken as the counting rate observed with no absorber in place. The background count observed on the decay electron register was almost entirely due to accidental or chance coincidences occurring between signals from counters *E* and anticoincidence signals. This fact was checked by carrying out long natural runs with no absorber, as well as by conducting short runs in which artificial anticoincidences were rapidly fed into the circuit while counters *E* were operating normally. In both cases, one delayed count was recorded for approximately every 700 anticoincidences.

The delayed counting rate from positive mesotrons does not vary greatly for the different absorbers. Undoubtedly, in the case of boron, where not much material was available, the rate was limited by the number of mesotrons stopped in the boron and, in the case of iron, the limiting factor was the short range of the decay electrons compared to the thickness of absorber used. The carbon and iron absorbers were chosen to be of approximately the same total size and weight. The fact that the positive delayed counting rates are the same for both these absorbers indicates

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[6] H. Jones, Rev. Mod. Phys. **11**, 235 (1939); D. J. Hughes, Phys. Rev. **57**, 592 (1940); G. Bernardini, M. Conversi, E. Pancini, E. Scrocco, and G. Wick, Phys. Rev. **68**, 109 (1945).

roughly that the decay of positive mesotrons is not affected by atomic number.

In order to compare the delayed counting rates from positive and negative mesotrons, the extreme right column has been corrected for the positive mesotron excess. This positive-excess correction was taken as that determined from the anticoincidence counting rate for each absorber.

The delayed counting rate results obtained from the carbon and iron absorbers agree with the results obtained by other investigators for these absorbers. For carbon, the corrected decay electron counting rates from positive and negative mesotrons are almost equal; considering the attached errors, the rates might be taken as equal. However, for iron, the delayed counting rate from negative mesotrons is the same as the background rate; this indicates that no negative mesotrons, or very few, exist longer than 2.3 microseconds after being stopped in the iron, and that the probability of capture per second greatly exceeds the probability of the normal (positive) decay.

The new absorbers, boron and aluminum, investigated in this experiment show the same results as carbon and iron, respectively. A correction has been applied to the negative delayed counting rate from boron on account of the iron container. The iron container accounted for 25 percent of the total absorber weight, and an estimated correction has been made on this weight basis. It is evident from these results that the transition element or element in which the decay constant (for positive mesotrons) equals the capture probability per second (for negative mesotrons) lies between carbon and aluminum. The transition zone is being investigated in further experiments.

The corrected delayed counting rate for positive mesotrons is observed to be slightly higher than that for negative mesotrons for the boron and carbon absorbers. Because of the large error, it is difficult to tell if this fact is significant or not. It means either that the correction for the positive excess is not large enough or that capture processes occur to a small extent in these light elements.

In order to check scattering phenomena, two short runs were taken in the case of the iron and carbon absorbers with no magnetic field. In order to minimize scattering the counter sets A, B, C, and D were placed so that a particle traveling in a straight line could not possibly pass through all of these counter sets. Considerable scattering is in evidence by the rather high coincidence and anticoincidence rates. However, with magnetic field, there is evidence that practically complete cut-off is obtained for mesotrons of the opposite sign. This is indicated by the fact that the delayed counting rate from negative mesotrons for the aluminum and iron absorbers is the same as that with no absorber. If positive mesotrons were scattered into the above absorbers when the magnetic field was set for negative mesotrons, the delayed counting rate would be expected to be above the background rate. These arguments also indicate that with magnetic field the anticoincidence counting rate is largely due to mesotrons of only one sign.

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