Los Alamos Scientific Laboratory of the University of California under Government Contract No. W-7405-eng-36, and the information contained therein will appear in Division V of the National Nuclear Energy Series (Manhattan Project Technical Section) as part of the contribution of the Los Alamos Laboratory.

APPENDIX

Figure 2 shows that the plate of the 5th "Higginbotham" Scaler was tapped and the signal fed to the vertical sweep plates of a blue-screen 5-inch DuMont oscillograph, Model 247. On the horizontal plates a specially built linear sweep was imposed and adjusted to a frequency of 1000 cycles/second. The screen was photographed by means of a continuously moving film, with the film moving vertically. The camera used was a General Radio Company oscillograph camera. The developed films showed a pattern like the sample shown in Fig. 16.

This pattern can be interpreted easily, since the first stage of the scaler contains a "flip-flop" circuit, and consequently its output changes from a maximum to a minimum and back to a maximum with successive pulses. Thus a shift of the height of the line on the scope (or film) will indicate that a pulse has registered. It should be clearly understood that with the use of this scheme the length of time between "breaks" (i.e., shifts in line-height) is the time elapsed between the appearance of two consecutive pulses and not the duration of a single pulse.

It is important that the sweep return be very fast in order that pulses may not be lost between the end of one and the beginning of another sweep. Since a signal pulse in between two sweeps is easily detected because of the shift in line-height, and, further, since two pulses within that time are rather unlikely because of the limitations in the resolving time of the amplifier, this sweep was found entirely adequate. Both the sweep and incoming signal were put directly on the respective sets of plates of the oscilloscope in order to by-pass the comparatively long time constants of the internal scope amplifiers. The incoming pulse height was regulated by means of a volume control between scaler and oscilloscope. It was so adjusted as to make the pulse height about a quarter of the distance between consecutive sweeps on the film, as can be seen in Fig. 16. This volume control had to be varied, of course, when a different film speed was used. The developed film is easily read on a Recordak Microfilm Reader.

PHYSICAL REVIEW VOLUME 74, NUMBER 10 NOVEMBER 15, 1948

The Capture Probability of Negative Mesotrons*

HAROLD K. TICHO
Department of Physics, University of Chicago, Chicago, Illinois
(Received August 5, 1948)

Disintegration curves of positive and negative mesotrons stopping in H_2O, NaF, Mg, Al, and S have been determined. The relative counting rates of positive and negative disintegration electrons support the view that the change of the mean life of negative mesotrons can be interpreted as due to a competition between the processes of spontaneous disintegration and nuclear capture. The mean-life values of positive mesotrons in the various materials are in agreement and yield a mean of $\tau_+ = 2.11 \pm 0.10$ μsec. From the mean life values of negative mesotrons the capture probabilities of mesotrons in the neighborhood of the absorber nuclei are calculated and shown to obey an empirical law of the form kZ^a with $a = 3.7 \pm 0.85$.

INTRODUCTION

TWO years ago, the author carried out a determination of the mean life of cosmic-ray mesotrons at an altitude of 11,500 feet[1] to investigate whether there might exist a variation of the mean life with altitude. The experimental method was similar to that used by Nereson and Rossi.[2] The absorber stopping the mesotrons was aluminum, and the mean life obtained was 1.78 ± 0.10 μsec. However, since a sea level check of the apparatus also yielded a value slightly lower than 2.15 ± 0.07 μsec., the best sea level value of Nereson and Rossi, an altitude variation of the mean life could not be considered as established. When the results of the experiment of Conversi, Pancini, and Piccioni on the disintegration of negative mesotrons in light materials became known,** it seemed more reasonable to

* Assisted by the joint program of the Office of Naval Research and Atomic Energy Commission.
[1] H. Ticho, Phys. Rev. **72**, 255 (1947).
[2] N. Nereson and B. Rossi, Phys. Rev. **64**, 199 (1943).

** Private communication by Prof. Amaldi.

attribute the reduced values of the mean life *both* at sea level and at the high altitude to a contribution to the disintegration curve of *negative* mesotrons with an *apparently* shorter mean life.[3] Ticho and Schein[4] calculated that such a shortened mean life of negative mesotrons would result if the probabilities for capture and spontaneous disintegration were comparable and if the two processes proceeded independent of each other.

In 1940, Tomonaga and Araki[5] calculated on the basis of meson theory that mesotrons stopping in a solid absorber should be captured by the nuclei within 10^{-12} second. This time interval is small compared to the mean life of mesotrons; hence, they concluded that *all negative* mesotrons stopping in a solid absorber should be captured. Positive mesotrons are repelled by the Coulomb field of the absorber nuclei; consequently they should disintegrate. Experiments by Rasetti,[6] Nereson and Rossi,[2] and Ticho[1] seemed to confirm this prediction. These authors found that the counting rate of observed disintegration electrons was roughly one-half of the counting rate of mesotrons stopping in the absorber. This was interpreted as being due to the fact that while in the cosmic radiation near sea level positive and negative mesotrons are about equally abundant, only the positive mesotrons give rise to disintegration electrons. For this determination, the authors mentioned above used aluminum absorbers; but because of the uncertainty in the range of the disintegration electrons, the results merely indicated a trend.

This qualitative agreement with theory disappeared when Conversi, Pancini, and Piccioni[7] actually separated positive and negative mesotrons by means of magnetized iron bars and showed that while in iron, as predicted, only positive mesotrons disintegrated, in carbon disintegrations of both positive and negative mesotrons occurred in about equal numbers. This result was later confirmed by Sigurgeirsson and Yamakawa,[8] and Valley.[9] These authors also proved the existence of this effect in other light materials.

Such a result could be interpreted in two ways. The interval between the time when the negative mesotron enters the absorber and the time when it stops close to the nucleus may be comparable to the natural mean life; or, the probability for capture of a negative mesotron within the range of nuclear forces may be comparable to the probability for spontaneous disintegration.

The processes, by which a heavy charged particle continues to lose energy when it does not have sufficient energy to cause ionization or excitation of the absorber nuclei, were investigated by Wheeler,[10] Fermi, Teller, and Weisskopf,[11] and discussed in detail by Fermi and Teller.[12] Fermi and Teller[12] showed that both in conductors and insulators a mesotron of 2000 ev loses the remainder of its kinetic energy and drops into a mesotronic K-shell within 10^{-12} second. This time interval is negligible compared to the mean life and hence the first interpretation above must be abandoned. It was shown,[11] however, that the second interpretation implies disagreement with meson theories by a factor of 10^{12}.

The present experiments were carried out to investigate the disintegration of negative mesotrons in more detail—to establish conclusively the existence of a change in their mean life and to examine the dependence of this change of the mean life upon the atomic number Z of the absorber.

ANALYSIS OF THE MEAN-LIFE CHANGE

Let N_0^- be the number of negative mesotrons stopping in an absorber. Within 10^{-12} second they lose the remainder of their energy and fall into K-orbits of the absorber nuclei. They may disappear from this orbit in two ways: they may disintegrate spontaneously and eject disintegration electrons or they may be captured by the nucleus. According to Ticho and Schein,[4] the number dN^-, disappearing in a time interval dt is proportional to the sum of the probabilities per unit time for disintegration λ and for capture Λ,

$$-dN^- = (\lambda + \Lambda)N^- dt. \quad (1)$$

[3] H. Ticho, Phys. Rev. **71**, 463 (1947).
[4] H. Ticho and Marcel Schein, Phys. Rev. **72**, 248 (1947).
[5] S. Tomonaga and G. Araki, Phys. Rev. **58**, 90 (1940).
[6] F. Rasetti, Phys. Rev. **60**, 198 (1941).
[7] M. Conversi, E. Pancini, and O. Piccioni, Phys. Rev. **71**, 209 (1947).
[8] T. Sigurgeirsson and A. Yamakawa, Phys. Rev. **71**, 319 (1947).
[9] G. Valley, Phys. Rev. **72**, 772 (1947).
[10] J. A. Wheeler, Phys. Rev. **71**, 320 (1947).
[11] E. Fermi, E. Teller, and V. Weisskopf, Phys. Rev. **71**, 314 (1947).
[12] E. Fermi and E. Teller, Phys. Rev. **72**, 399 (1947).

If $a(Z)$ is the probability of *observing* a disintegration electron emitted in the absorber and $b(Z)$ the probability of *observing* the particles, if any, emitted immediately after capture,

$$N_{\mathrm{obs}}^-(t) = N_0^-[(\lambda a(Z) + \Lambda b(Z))/(\lambda+\Lambda)] \times \exp[-(\lambda+\Lambda)t]. \quad (2)$$

Thus *both processes* proceed with a *changed mean life* $1/(\lambda+\Lambda)$. For positive mesotrons, which presumably disintegrate with the same constant λ as the negative ones and yield disintegration electrons of the same energy, the corresponding equation reads

$$N_{\mathrm{obs}}^+(t) = N_0^+ a(Z)\exp(-\lambda t). \quad (3)$$

From these two equations, at $t=0$,

$$N_{\mathrm{obs}}^+/N_{\mathrm{obs}}^- = [1/\epsilon][(\lambda+\Lambda)/(\lambda+c(Z)\Lambda)]. \quad (4)$$

Here $\epsilon = N_0^-/N_0^+ = 0.82$ is the ratio of the intensities of mesotrons of opposite polarities in the cosmic radiation at sea level, and $c(Z) = b(Z)/a(Z)$. Ordinarily, it is assumed that in an apparatus of the type to be described no observable particles result from capture. Hence, $b(Z)=c(Z)=0$.

$$\epsilon(N_{\mathrm{obs}}^+/N_{\mathrm{obs}}^-) = (\lambda+\Lambda)/\lambda = \tau_+/\tau_-. \quad (5)$$

In the last equation $\tau_+ = 1/\lambda = 2.15$ μsec.,

$$\tau_- = 1/(\lambda+\Lambda).$$

According to Wheeler,[10] the capture probability should increase approximately with the fourth power of the atomic number Z of the absorber. The probability for capture per unit time is given by the product of the probabilities Λ_n, that a mesotron which is the K-orbit is in the nucleus, and Λ_c, that a mesotron within the nucleus is captured

$$\Lambda = \Lambda_c\Lambda_n = \Lambda_c\int_0^{r_0} \psi_0^*\psi_0 d\tau \simeq 4r_0^3\Lambda_c/3a_0^3. \quad (6)$$

In the equation above, r_0 is the radius of the absorber nucleus, ψ_0 is the wave function of the mesotron in the K shell, and a_0 the Bohr radius of the orbit. Substituting appropriate numbers

$$\Lambda = 4.6\times 10^{-7}\Lambda_c Z^4. \quad (7)$$

DISCUSSION OF THE INSTRUMENT

A cross-sectional view of the counter tube assembly is shown in Fig. 1. The apparatus was designed to concentrate either positive or negative mesotrons by means of a magnetized-iron lens and to record the individual lifetimes of those mesotrons which stop in the absorber. The measurement was performed by determining the time interval between the firing of counter tube S and any one of the counter tubes D, provided the pulse from counter tube S was in coincidence with an anticoincidence (C_A, C_B, C_C, $-A$). The anticoincidence counter tubes A did not cover the solid angle subtended by C_A, C_B, and C_C completely in the axial direction. They served mainly to reduce the counting rate, caused by single particles passing through the entire apparatus. The counter tubes D were situated just outside the solid angle defined by the counter tubes C_B and S. It appeared preferable to have the beginning of the time interval measurement started by the pulse from a single counter tube S, rather than by the anticoincidence pulse (C_A, C_B, C_C, $-A$). Any counter tube exhibits *random* natural time lags between the time when the ionizing particle passes through it and the time when the pulse is registered. A coincidence circuit can operate only after it receives the last pulse from its associated counter tubes; the *spread* of time intervals at which this *last* pulse occurs is therefore neces-

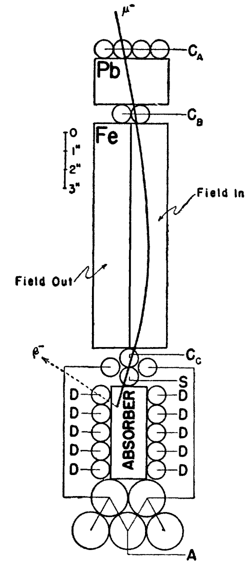

FIG. 1. Cross-sectional view of the magnetic lens, absorber, and counter tube assembly.

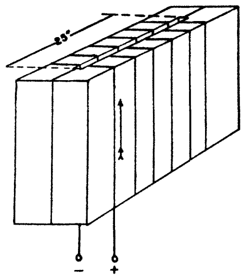

FIG. 2. Schematic diagram of the magnetic lens.

sarily larger than the *spread* of delays of a single counter tube.

The Geiger-Mueller counter tubes were of the all-metal type and were filled with a 90 percent argon, 10 percent alcohol mixture to a total pressure of 12.6 cm Hg. The 1-in. counter tubes in Fig. 1 had an active length of 24 in.; the 2-in. anticoincidence counter tubes had an active length of 36 in. The center wire was made of 5-mil Kovar metal. The D counter tubes had a 0.38-mm brass cylinder cathode. All the counter tubes were operated close to the upper ends of their plateaus.

Mesotrons of one polarity were selected by means of a magnetic lens, similar to the one used by the Rome group.[13] This lens, shown schematically in Fig. 2, consisted of two Armco magnetic iron bars which were placed side by side to form a complete magnetic circuit and hollowed out on the inside faces to accommodate the coil windings. With the magnetic field as indicated in Fig. 1, low energy negative mesotrons are concentrated on the absorber below; by reversing the exciting current in the coils the magnetic field could be reversed so that positive mesotrons were collected and negative ones dispersed. The magnetic field in the bars was 14,700 gauss, close to saturation for Armco iron. A representative trajectory for a field of 14,700 gauss is shown in Fig. 1. Obviously, high energy (>1 Bev) mesotrons pass through the lens whatever their polarity; however, such high energy particles cannot stop in the absorber below. In fact, when the lens concentrates mesotrons of *one* polarity, mesotrons of the *opposite* polarity can establish a coincidence (C_A, C_B, C_C, S) only if, upon *emerging* from the lens, their residual energy is *larger than* 160 Mev. Mesotrons of such large energies could not stop in any one of the absorbers which were employed in this series of experiments. The H_2O, NaF, Mg, Al, and S absorbers all had a thickness of 12.5 cm; the mesotron energies, corresponding to a range of 12.5 cm in the absorbers are listed in column 4 of Table I. The conclusions regarding the exclusion of mesotrons of the undesired polarity are rendered less definite by the scatterings which the mesotron may undergo during its passage through the iron. It has been shown[14] that in a

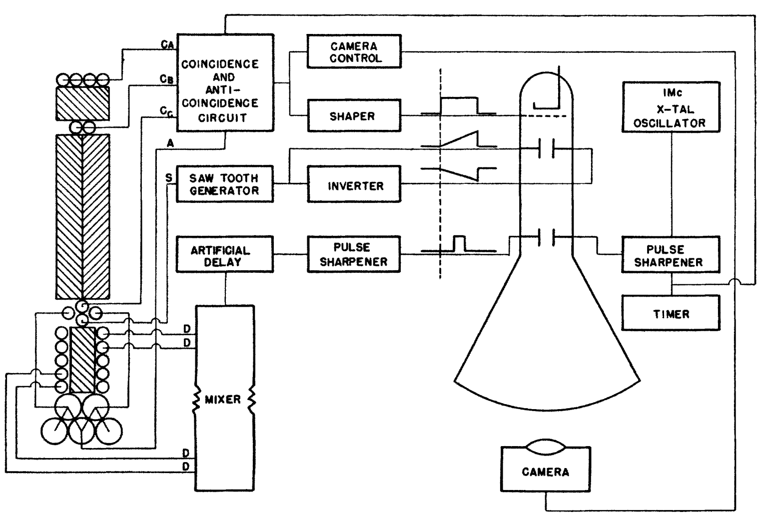

FIG. 3. Block diagram of the timing circuit.

[13] Bernardini, Conversi, Pancini, Scrocco, and Wick, Phys. Rev. 68, 109 (1945).
[14] G. Bernardini, M. Conversi, E. Pancini, and G. C. Wick, La Ric. Scient. 12, 1227 (1941).

lens of this sort the mean angle of scattering is about 0.4 of the angle of magnetic deflection. The effectiveness of the lens in barring mesotrons of the "wrong" polarity will be discussed further as the results of the measurements are presented.

A block diagram of the timing circuit is shown in Fig. 3. The pulses from the counter tubes C_A connected in parallel, counter tubes C_B, counter tube C_C, and counter tubes A are applied to an anticoincidence circuit which then "turns on" the electron beam of a 5CP11A cathode-ray tube and also actuates the camera rewinding circuit. The beam remains turned on for 7 μsec. The pulse from counter tube S actuates a saw-tooth generator which produces a balanced linear sweep which lasts 8 μsec. The pulses from the ten counter tubes D are combined in a cathode-follower mixing circuit to avoid the reduction in pulse rise speed due to increased shunt capacity which results when many counter tubes are operated in parallel. The pulse from the mixer is applied to a delay circuit of the type discussed by Chance.[15] This circuit delays the pulse for a fixed time interval before it is applied to one of the vertical deflecting plates of the oscillograph tube. This delay circuit permits the zero point of the time scale to be set so that the pulse of a counter tube D always appears on the sweep *after* the anticoincidence pulse had turned on the electron beam. The zero was normally set to about 1 μsec. from the starting point of the sweep. Thus by means of this circuit *all* delays between 0 and 6 μsec. could be recorded. The traces were photographed on Super XX film by means of a special camera which employed a coated Ektar f:2 lens.

Since in this apparatus the anticoincidence monitor circuit and the circuits starting and terminating the time interval measurement were electrically independent, the calibration consisted of two entirely separate steps: (a) the calibration of the writing speed of the sweep and (b) the determination of the zero point of the time scale. The sweep was calibrated automatically every hour, when for one minute the timer in Fig. 3 opened a gate such that marker pips derived from a 1-megacycle crystal oscillator were applied to the one remaining deflection plate of the

TABLE I.

1 Material	2 Density	3 Range	4 Energy
H_2O	1.00 g/cm³	12.5 cm	52 Mev
NaF	1.30 g/cm³	12.5 cm	56 Mev
Mg	1.74 g/cm³	12.5 cm	68 Mev
S	2.07 g/cm³	12.5 cm	75 Mev
Al	2.70 g/cm³	12.5 cm	99 Mev

cathode-ray tube. During this one-minute period the timer also disconnected the anticoincidence tubes A to increase the counting rate. Figure 4 shows a sample of the photographic record of the timing circuit; sweep calibration traces appear at the bottom. In the six months, during which the measurements were carried out, the writing speed of the sweep never varied by more than two percent over the 24-hour periods during which the apparatus ran unattended.

The zero point of the time scale was determined at the beginning and at the end of each 24-hour period by disconnecting the counter tubes A, removing the absorber from its place, and transferring one of the counter tubes D into the solid angle defined by the telescope C_A, C_B,

c
a
a
a
b
d
d

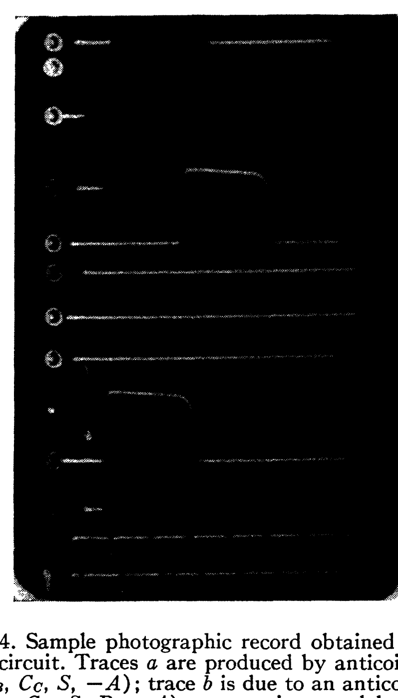

FIG. 4. Sample photographic record obtained from the timing circuit. Traces a are produced by anticoincidences (C_A, C_B, C_C, S, $-A$); trace b is due to an anticoincidence (C_A, C_B, C_C, S, D, $-A$); trace c is caused by an anticoincidence (C_A, C_B, C_C, S, $-A$) and a disintegration electron ejected with a delay of 1.75 μsec.; traces d are sweeps with 1-μsec. marker pips.

[15] Britton Chance, Rev. Sci. Inst. 17, 396 (1946).

C_C, and S; then counter tubes S and D should be tripped simultaneously by single particles passing through the entire apparatus, and zero time intervals should be recorded. However, due to the random delays in the counter tubes themselves, there results, instead of a single value, a distribution of readings. The average of this distribution was defined as the "true zero." Data were rejected if the averages obtained at the beginning and at the end of a 24-hour run differed by more than 0.05 μsec.; in general, the averages agreed within 0.03 μsec. The delays due to the lags in the counter tubes are, of course, independent of the time when the two counter tubes are tripped. Therefore, it is proper to consider the delay distribution curve obtained with a true delay of zero as the error curve which applies to any time interval reading. Such a delay distribution curve, with the data of all the counter tubes D added, is shown in Fig. 5; the probable error is 0.05 μsec.

Aside from indicating the error in each lifetime measurement, the delay distribution curve puts a limit on the *smallest* time intervals for which a disintegration curve obtained by this apparatus remains valid. First of all, an observed delay between 0 and 0.25 μsec. can be produced by a lag in one of the counters D associated with a simultaneous event such as a shower. Furthermore, Rossi and Nereson[16] have shown that if the delay distribution curve is represented by $f(t')$, a function which is zero for $t_1<t'$, and for $t_2>t'$, then the decay curve is given by

$$N(t)=N_0\exp(-\lambda t)\int_{-\infty}^{+\infty} f(t')\exp(\lambda t')dt',$$

provided $t>t_1$. In the region $t>t_1$ the counter lags affect the decay curve only in changing its amplitude; in the region $t<t_1$, the integral becomes a function of t_1. In the experiments to be described, only time interval measurements larger than 0.35 μsec. were accepted as due to disintegrations.

The multiplicative constant

$$F(\lambda)=\int_{-\infty}^{+\infty} f(t')\exp(\lambda t')dt'$$

must be considered if counting rates of disintegration electrons resulting from decay processes with *different* life times are to be compared. If the delay distribution curve in Fig. 5 is represented by a Gaussian error curve with a precision modulus $h=10^7$ sec.$^{-1}$, then $F(\lambda)=\exp(\lambda^2/4h^2)\simeq 1+\frac{1}{4}(\lambda/h)^2$. The smallest mean life obtained in this series of measurements is about 0.5 μsec., hence $F(\lambda)\simeq 1.010$. This correction is small compared to other errors and will be neglected.

On the average, 22 anticoincidences (C_A, C_B, C_C, $S-A$) were registered per hour. Of those, 15 were not accompanied by any pulse from the counter tubes D, in six cases one of the counter tubes D was discharged simultaneously, and one anticoincidence was accompanied by a delayed firing of a counter tube D due to a disintegration. From the 15 simple anticoincidences per hour and the counting rate of 60 pulses per second of all the counter tubes D in parallel one deduces that the rate of spurious delays, caused by an anticoincidence (C_A, C_B, C_C, $S-A$) and a

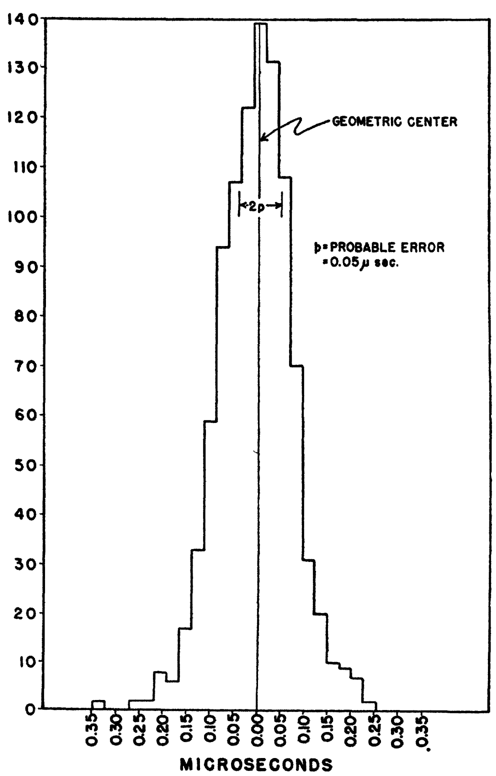

FIG. 5. Frequency distribution of observed time intervals between the firing of two G-M counters when they are actuated simultaneously.

[16] B. Rossi and N. Nereson, Phys. Rev. **62**, 417 (1942).

TABLE II.

1 Material	2 Atomic number	3 Charge	4 Time of observation in hours	5 Total number of decay electrons observed	6 Correction factors*	7 Counting rate per hour ϵN_+, N_-	8 Mean life τ in microseconds	9 Capture probability $\times 10^{-5}$ sec.**	10 τ_+/τ_-**	11 $\epsilon N_+/N_-$
H_2O	8***	+	77.5	135±12	0.82/0.75	1.90±0.16	2.19±0.30		1.14±0.09	1.20±0.12
		−	277.8	333±18	1.00/0.76	1.58±0.09	1.89±0.15	0.65±0.4		
NaF	10.1†	+	102.0	174±14	0.82/0.72	1.93±0.14	2.14±0.27		1.68±0.17	1.66±0.17
		−	201.3	171±13	1.00/0.73	1.16±0.09	1.28±0.12	3.2 ±0.6		
Mg	12	+	158.3	307±18	0.82/0.75	2.11±0.12	2.14±0.21		2.24±0.16	1.79±0.14
		−	445.5	330±18††	1.00/0.63	1.18±0.06	0.96±0.06	5.8 ±0.6		
Al	13	+	137.4	339±18	0.82/0.73	2.75±0.15	2.04±0.18		2.9 ±0.3	2.5 ±0.2
		−	397.1	256±16††	1.00/0.59	1.10±0.07	0.75±0.07	8.7 ±1.1		
S	16	+	105.5	202±14	0.82/0.79	2.00±0.14	2.13±0.25		4.0 ±0.7	3.5 ±0.4
		−	473.9	167±13††	1.00/0.63	0.57±0.06	0.54±0.12	13.9±3.3		

* Numerator corrects positive excess, denominator corrects for decay times beyond the limits of the time interval under observation.
** $\tau_+ = 2.15 \pm 0.07$ μsec. used throughout.
*** Only oxygen is effective. See text.
† Average Z according to Fermi and Teller (reference 12).
†† Corrected for an inefficiency of the magnetic lens of four percent.

subsequent, unrelated firing of a counter tube D, was 4.5×10^{-3} per hour.

EXPERIMENTAL RESULTS

In the course of this series of experiments the mean life of positive and negative mesotrons was investigated in water, sodium fluoride, magnesium, aluminum, and sulfur. The counting rates of positive and negative disintegration electrons were determined at the same time. Table II summarizes the results obtained. All the mean-life values and their errors, listed in column 8, except those given for negative mesotrons stopping in aluminum and in sulfur, were computed by means of the statistical method of Peierls.[17] The mean-life data of positive mesotrons from all the materials investigated combined yield $\tau_+ = 2.11 \pm 0.10$ μsec., in good agreement with the best value reported by Nereson and Rossi,[2] namely 2.15 ± 0.07 μsec.

The total numbers of positive and negative disintegration electrons observed in each material are listed in column 5. In order to make the counting rates of positive and negative disintegration electrons coming from each material comparable, they had to be corrected so that they referred to equal numbers of mesotrons stopping in the material. The correction factor, in column 6, shows how this correction was applied; the numerator normalizes the counting rate with respect to the excess of 20 percent of positive mesotrons present in the hard component at sea level—the denominator corrects for

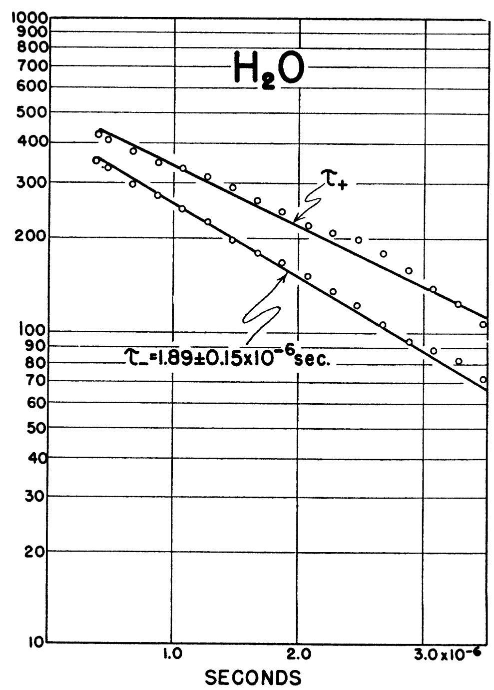

FIG. 6. Disintegration curves of positive and negative mesotrons stopping in water. The disintegration curve of negative mesotrons is plotted accurately; the disintegration curve of positive mesotrons is plotted normalized, such that both curves represent the same numbers of mesotrons stopping in the absorber.

[17] R. Peierls, Proc. Roy. Soc. 149, 467 (1935).

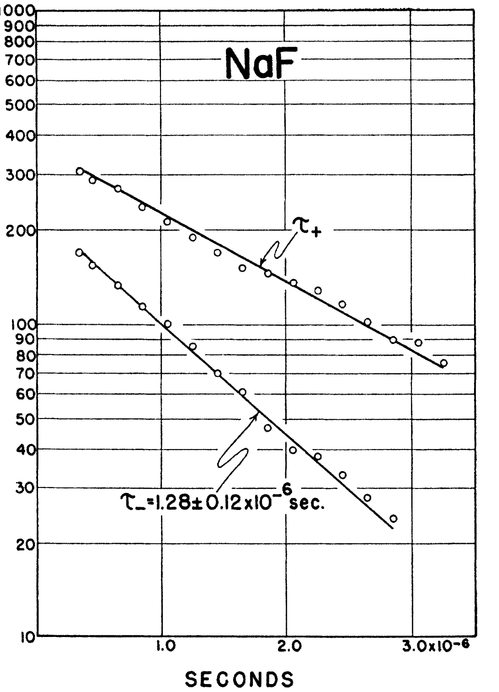

FIG. 7. Disintegration curves of positive and negative mesotrons stopping in sodium fluoride. The disintegration curve of negative mesotrons is plotted accurately; the disintegration curve of positive mesotrons is plotted normalized, such that both curves represent the same numbers of mesotrons stopping in the absorber.

disintegrations corresponding to decay times outside the time interval under observation.

In the *integral* disintegration curves which follow the data pertaining to negative mesotrons have been plotted accurately; the data for positive mesotrons were plotted normalized to those of the negative mesotrons so that both curves refer to the same number of positive and negative mesotrons stopping in the absorber.

Figure 6 shows the disintegration curves with water used as absorber. The water was kept in a copper container of 0.5 g/cm^2 wall thickness. When the mesotron stops in the vicinity of a hydrogen nucleus, the two particles form a neutral system and it is easily shown that within 2 μsec. this neutral system makes several thousand collisions with oxygen nuclei in which the mesotron may attach itself to the oxygen. Hence it may be safely assumed that all the disintegration electrons observed are due to mesotrons which disintegrated in the neighborhood of oxygen nuclei.[9] The mean life $\tau_- = 1.89 \pm 0.15$ μsec. therefore corresponds to the mean life of negative mesotrons stopping in oxygen.

The sodium fluoride absorber used to obtain the decay curves of Fig. 7 consisted of NaF powder pressed to a density of 1.3 g/cm^3 in a Bakelite container of 0.25 g/cm^2 wall thickness. Fermi and Teller[12] have shown that the probability that a mesotron stops in the neighborhood of any atom of a chemical compound is directly proportional to the atomic number of this atom. The mean life $\tau_- = 1.28 \pm 0.12$ μsec. may therefore be regarded as resulting when negative mesotrons are stopped in an absorber consisting of an element with $Z = 10.1$.

Figure 8 shows the disintegration curves of positive and negative mesotrons stopping in magnesium. From the disintegration curve of negative mesotrons one obtains $\tau_- = 0.96 \pm 0.06$ μsec.

When the mean life of negative mesotrons was measured in aluminum and in sulfur, the inefficiency of the magnetic lens in barring mesotrons of the opposite polarity became noticeable. This can be seen by examining the upper sets of

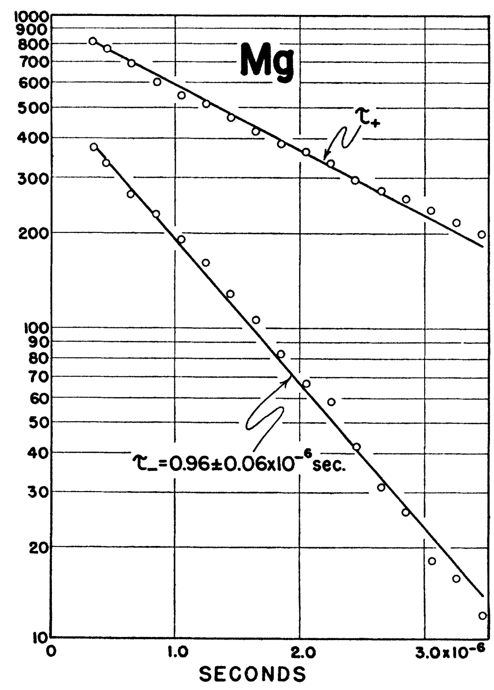

FIG. 8. Disintegration curves of positive and negative mesotrons stopping in magnesium. The disintegration curve of negative mesotrons is plotted accurately; the disintegration curve of positive mesotrons is plotted normalized, such that both curves represent the same numbers of mesotrons stopping in the absorber.

points on the decay curves of negative mesotrons in Figs. 9 and 10; in both cases after a time interval of about 1.5 μsec. more mesotrons seem to remain than the original slope of the disintegration curve would require. In either case the departure from linearity is only slightly outside the statistical error; but the fact that this deviation is observed *only* in the two cases when the negative mesotrons disappear most rapidly strongly suggests a slight admixture of positive mesotrons as the cause. Consequently, from the decay curves observed a decay curve was subtracted whose slope corresponded to 2.15 μsec. and whose amplitude was adjusted such as to make the difference curve linear. The lower sets of points in Figs. 9 and 10 were obtained by such a subtraction and they yield $\tau_- = 0.75 \pm 0.07$ μsec. for aluminum, and $\tau_- = 0.54 \pm 0.12$ μsec. for sulfur. This procedure appears less arbitrary in the light of the facts (a) that for *both* aluminum and sulfur it was necessary to assume an inefficiency of four percent to make the difference curves linear, and (b) that a short measurement in which the aluminum was replaced by an equivalent amount of lead, in which no negative mesotrons should disintegrate also yielded an inefficiency of the magnetic lens of four percent. Finally, in these two cases, the errors of the mean-life values have been increased beyond those given by Peierls' statistics such that they include the mean lives exhibited by the disintegration curves before the correction was applied. The mean life of negative mesotrons in aluminum is in good agreement with the result of Valley and Rossi,[18] 0.74 ± 0.17 μsec. The disintegration curve of negative mesotrons in magnesium has not been corrected for the inefficiency of the magnetic lens since here this correction is smaller than the statistical error; the correction *was applied* to the counting rate of disintegration electrons.

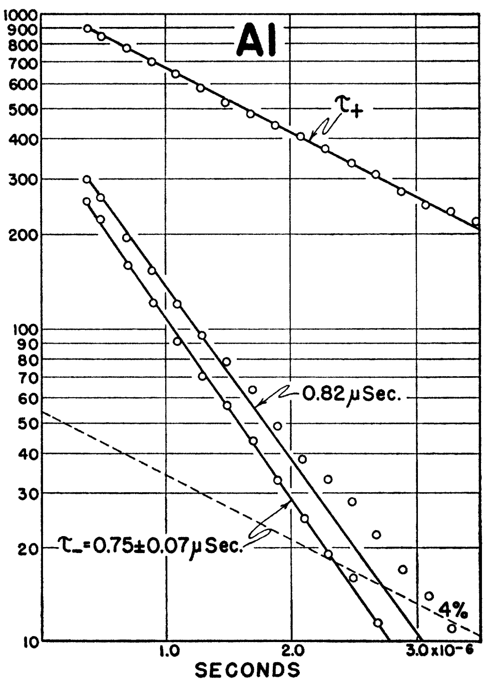

FIG. 9. Decay curves of positive and negative mesotrons stopping in aluminum. The curve whose slope corresponds to a mean life of 0.82 μsec. was obtained for negative mesotrons. The curve below is the same curve corrected for an admixture of four percent of positive mesotrons. The disintegration curve of negative mesotrons is plotted accurately; the disintegration curve of positive mesotrons is plotted normalized, such that both curves represent the same numbers of mesotrons stopping in the absorber.

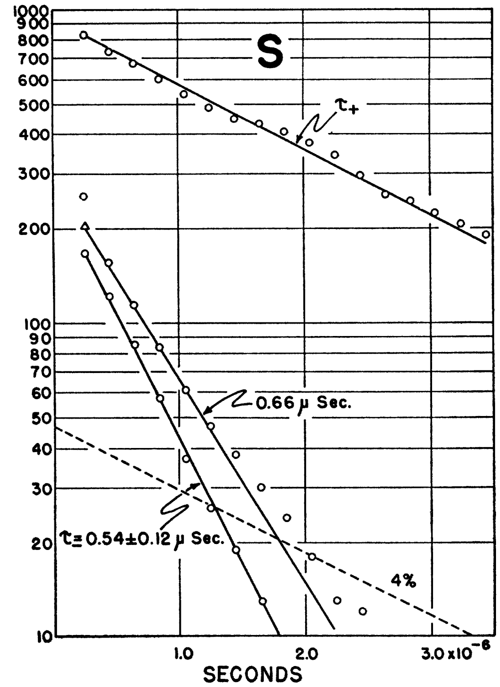

FIG. 10. Disintegration curves of positive and negative mesotrons stopping in sulfur. The curve whose slope corresponds to a mean life of 0.66 μsec. was obtained for negative mesotrons. The curve below is the same curve corrected for an admixture of four percent of positive mesotrons. The disintegration curve of negative mesotrons is plotted accurately; the disintegration curve of positive mesotrons is plotted normalized, such that both curves represent the same numbers of mesotrons stopping in the absorber.

[18] G. E. Valley and B. Rossi, Phys. Rev. **73**, 177 (1948).

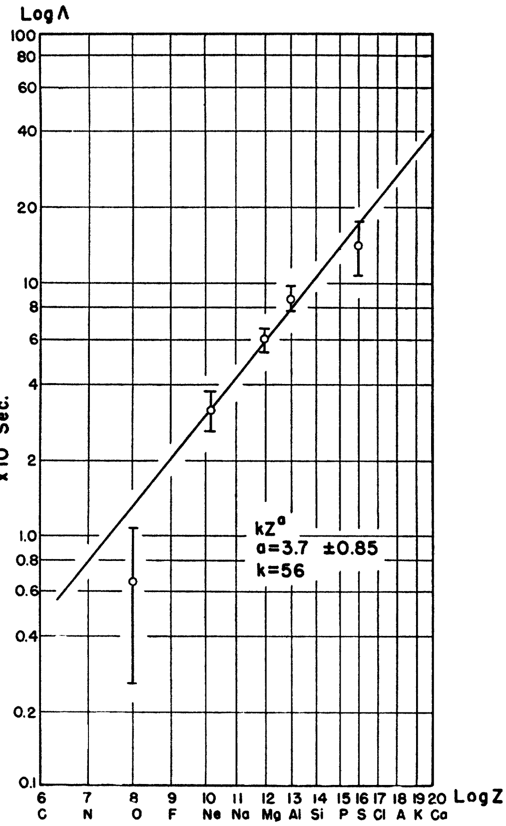

FIG. 11. The measured probabilities for nuclear capture per unit time plotted as a function of the atomic number, and a least squares curve of the form kZ^a fitted through the points.

For the mean-life measurements the sulfur was cast in a copper vessel of 0.5 g/cm^2 wall thickness. In this case it seemed very desirable to extend the time interval under observation into the region which was previously excluded because of the presence of natural counter tube lags. Hence the apparatus was operated without any absorber and the delays thus observed were subtracted from the disintegration curve *before* the correction for the inefficiency of the magnetic lens was applied. The triangular point at 0.25 μsec. represents the result of this subtraction.

In the course of these measurements the equipment was moved from one laboratory to another; furthermore, the sulfur measurement was performed with nine D counter tubes only. For these reasons the absolute counting rates in the various materials investigated cannot be compared.

CONCLUSIONS

From the mean-life values of negative mesotrons the capture probabilities Λ, mentioned earlier, were calculated for the materials investigated using $\tau_+ = 2.15 \pm 0.07$ μsec. They are tabulated in column 9 of Table II and plotted in Fig. 11. The points have been fitted using the method of least squares to a curve of the form kZ^a and the resultant constants are $a = 3.7 \pm 0.85$, and $k = 56$. In this fit the error in k is very large due to the power law character of the relationship. The result for a is in rough agreement with the prediction of Wheeler[10] that a should be approximately equal to 4.

The ratios of the mean lives τ_+/τ_- and the ratios of the corrected counting rates $\epsilon N_+/N_-$ are listed, respectively, in columns 10 and 11 of Table II and plotted in Fig. 12. In all cases, except in that of magnesium, the two ratios are the same within experimental error, in agreement with Eq. (5) given earlier. The large difference between the two ratios in aluminum, reported by Valley and Rossi,[18] has not been observed. This result also makes a completely different

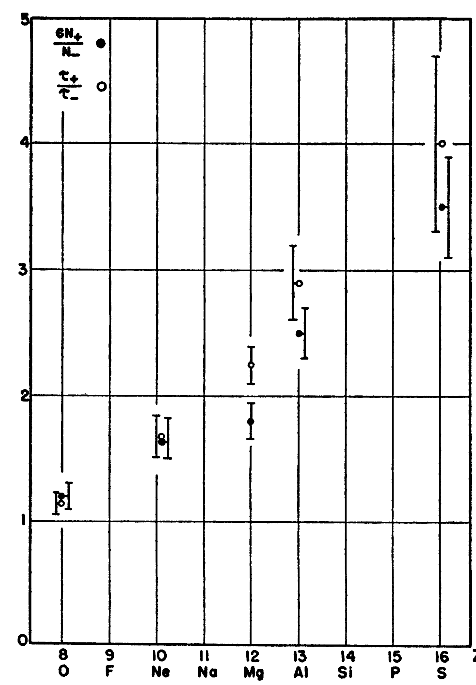

FIG. 12. The ratios of the mean lives τ_+/τ_- (empty points) and the ratios of the corrected counting rates $\epsilon N_+/N_-$ (solid points) plotted *vs.* the atomic number of the absorber.

interpretation of the decay of negative mesotrons in the neighborhood of an atomic nucleus which was suggested by Epstein, Finkelstein, and Oppenheimer[19] seem rather improbable. These authors have suggested that the change of the mean life may be due to an *acceleration* of the decay process by the intense electrostatic field of the nucleus. This hypothesis has two consequences of interest here: it follows that the counting rates of positive and negative disintegration electrons should be equal, and that the capture probability should increase with the *fifth* power of the atomic number. Neither of these two consequences was verified here.

Although the ratios τ_+/τ_- and the ratios $\epsilon N_+/N_-$ are generally within statistical error, there seems to be a trend for $\epsilon N_+/N_-$ to be somewhat smaller than τ_+/τ_- Such a discrepancy would result if the nucleus, *immediately* after it captures a mesontron, could emit a particle which could discharge a counter tube. In such a case, of the equations discussed previously (4) instead of (5) would apply. Figure 13 shows curves for the ratio $\epsilon N_+/N_-$ for various values of $c(Z)$ with c assumed constant for simplicity. The experimental results are not inconsistent with the possibility that a particle is emitted after capture. However, because of the errors involved here further experiments will be required to decide this question.

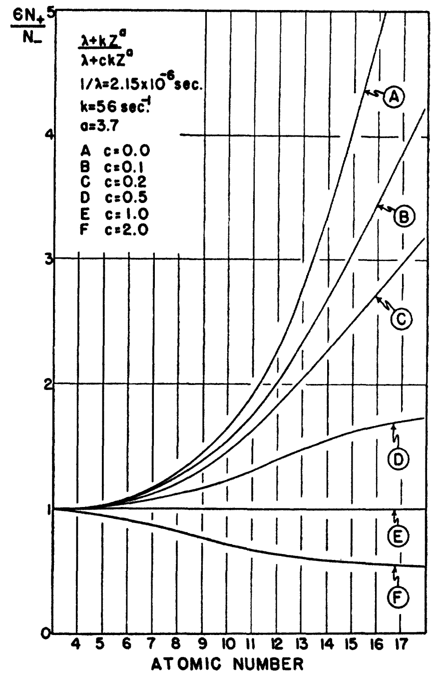

FIG. 13. Ratio of the counting rates of positive and negative disintegration electrons as a function of the atomic number of the absorber with the ratio of observabilities of particles emitted by the nuclear upon mesotron capture, and disintegration electrons as a parameter.

The writer wishes to express his gratitude to Professor Marcel Schein for his continuing interest and guidance throughout the course of these experiments. It is also a pleasure to acknowledge the assistance of Mr. Ivar Kalberg, who designed the automatic camera, and of Mr. David M. Haskin, who built the G-M counters used in this experiment.

[19] S. T. Epstein, R. J. Finkelstein, and J. R. Oppenheimer, Phys. Rev. **73**, 1140 (1948).

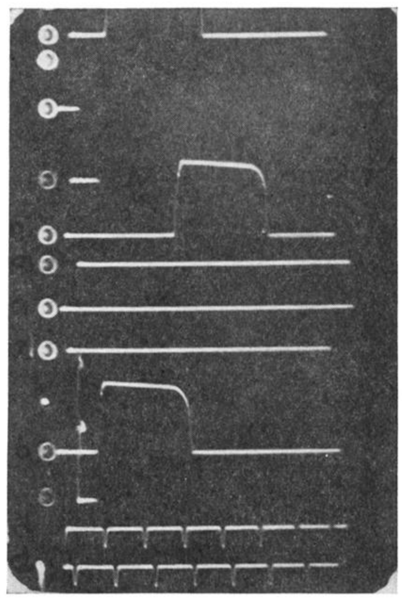

FIG. 4. Sample photographic record obtained from the timing circuit. Traces *a* are produced by anticoincidences (C_A, C_B, C_C, S, $-A$); trace *b* is due to an anticoincidence (C_A, C_B, C_C, S, D, $-A$); trace *c* is caused by an anticoincidence (C_A, C_B, C_C, S, $-A$) and a disintegration electron ejected with a delay of 1.75 μsec.; traces *d* are sweeps with 1-μsec. marker pips.