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Electron Emitting Power of Stopped Mesons*

THORBJORN SIGURGEIRSSON** AND K. ALAN YAMAKAWA

Palmer Physical Laboratory, Princeton University, Princeton, New Jersey

I. INTRODUCTION AND TABULATION OF RESULTS

A YEAR ago we presented preliminary measurements which suggested a systematic trend with atomic number in the number of decay electrons emitted when sea level mesons of assorted electric polarities are stopped in various materials.[1] We have since considerably extended the measurements (Fig. 1.) We conclude that the division between elements of high and low electron emission comes in the neighborhood of atomic number $Z_0 \sim 10$. We have also found that the decay curves for mixed sea level mesons, 0.75 μsec. after the arrival of the meson, show a relatively small difference from element to element, as expected from simple theoretical arguments.

Our experiment was designed primarily to make a quick survey of the behavior of negative mesons as affected by the atomic number of the moderator. We therefore made no magnetic separation between mesons of the two polarities. We were able to assume that the unwanted positive mesons undergo decay in all substances because (a) the electrical repulsion of the nucleus prevents capture and because (b) the remarkable observation of Conversi, Pancini, and Piccioni[2] confirmed this conclusion about positive mesons in the case of iron and carbon, and showed that the unexpected difference between the behavior of mesons in the two materials was confined entirely to the negative mesons. In our experiment the decay electrons from the positives, of course, slightly complicate the interpretation of the results and decrease the attainable statistical accuracy of conclusions about negative meson decay. However, the counting rate is many times higher than that obtained in an arrangement employing magnetic separation.

In the time which has elapsed since our first report, there has of course been opportunity for other investigators to use the technique of magnetic separation to obtain in the case of certain elements results on the decay of negative mesons by themselves. Such results, where available, are plotted along with our own data in Fig. 2, where there are shown for comparison theoretical curves expected from the Z^4_{eff} power law of meson reaction probability.[3]

The results of our own measurements and those of others are seen to be consistent with a value of close to 10 for the atomic number, Z_0 of that idealized nucleus for which meson decay and the specifically nuclear meson disappearance reaction have equal probabilities. This constant provides a means to determine the strength of coupling of the meson field to the nucleus, as shown in detail in a following paper by Tiomno and Wheeler.[4]

The remainder of this paper contains a description of the experimental arrangement (Section II), procedures used in taking data (Section III), a detailed analysis of the data for sulfur (Section IV), and a summary of the data for other elements and of the corrections applied thereto (Section V).

II. EXPERIMENTAL ARRANGEMENT

A schematic diagram of the apparatus including a cross section of the counter arrangement is given in Fig. 3. A fifteen-cm layer of lead was placed above the counters to reduce the electron component of the cosmic radiation and to increase the number of slow mesons.[5]

The mesons are detected, as they enter the

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* The considerations in this paper on dependence of electron emitting power upon atomic number were briefly reported by J. A. Wheeler at the Pasadena Cosmic Ray Conference.

** Now at Department of Engineering, University of Iceland, Reykjavik.

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

[2] Conversi, Pancini, and Piccioni, Phys. Rev. **71**, 209 (1947).

[3] Measurements on the lifetime of magnetically separated negative mesons: G. E. Valley and B. Rossi, Phys. Rev. **73**, 177 (1948); H. Ticho and M. Schein, Phys. Rev. **73**, 81 (1948); H. Ticho, Phys. Rev. **73**, 492 (1948); J. A. Wheeler, Phys. Rev. **71**, 320 (1947); Rev. Mod. Phys. **21**, 133 (1949); J. Tiomno and J. A. Wheeler, Rev. Mod. Phys. **21**, 144 (1949).

[4] J. Tiomno and J. A. Wheeler, Rev. Mod. Phys. **21**, 153 (1949).

[5] G. T. Reynolds, Rev. Mod. Phys. **21**, 122 (1949).

moderator, by the two top counter trays (*I* and *II*). Each tray consists of two counters connected in parallel. The impulses from the two trays go to a preamplifier and then to a coincidence circuit which sends an impulse to the time measuring unit whenever *I* and *II* fire at the same time. Counter tray *III* consists of four counters in parallel and is used to detect the decay electrons as they come out of the moderator. The impulses from *III* go to a preamplifier and then to the time measuring unit. This unit records the lifetime of the meson brought to rest in the moderator as the difference in time between an impulse from the coincidence ($I\times II$) and the corresponding impulse from *III*.

The time measuring unit[6] consists of a 4-Mc oscillator, a gate circuit, and a counter. The counter measures and records the number of oscillations which take place between the arrival of the meson ($I\times II$) and the emergence of the decay electron (*III*), as follows:

The output of the oscillator is fed continuously to the gate circuit. The gate circuit is normally closed so that the oscillations are not counted by the counter. An impulse from ($I\times II$) opens the gate which then stays open for a maximum of 16 microseconds. (a) If *III* sends out an impulse within 16 microseconds, this impulse closes the gate. The counter measures the time interval in terms of the number of oscillations allowed through the gate in this interval of time. (b) If there is no impulse from *III* within 16 microseconds, the gate automatically closes and no record is made.

The time interval is automatically recorded on a strip of voltage sensitive paper in units of 0.25 microsecond.

Between the actual process of time measurement and the procedure just described there is one difference which is introduced to diminish the number of spurious short time delays. Sometimes events which are actually time coincident in $I\times II$ and in *III* appear as delays because of occasional slow collection of electrons in counter *III*. However, appropriate corrections for the spurious counts can be made as described later. It is found that the proportion of spurious delays greater than 0.5 μsec. is small and can be estimated. On the other hand, the fraction of observed delays less than 0.5 μsec. is sufficiently great that it was felt to be undesirable to record any such short time delays, whether spurious or real. The timer was spared the task of recording these delays by the simple procedure[7] of delaying by 0.5 μsec. the arrival at this unit of the electrical impulse from counter coincidence $I\times II$. Consider for example an impulse which starts out from *III* 0.4 μsec. after the $I\times II$ pulse. The *III* pulse gets to the timer 0.1 μsec. ahead of the $I\times II$ pulse. But the latter impulse is required to open the gate circuit before the time counting begins. Consequently the *III* pulse is not counted and the event is not recorded.

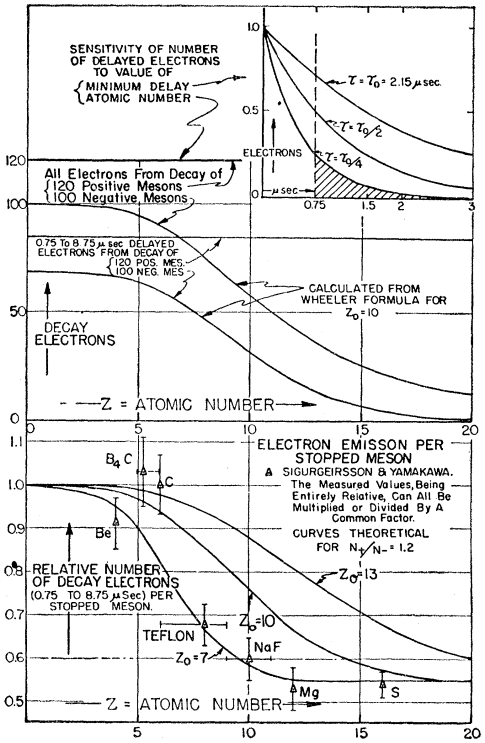

FIG. 1. Our results for relative electron emitting power of normal mixture of positive and negative mesons stopped in various moderators, compared with theoretical results expected for various values of Z_0 on the basis of the Z^4_{eff} law. The curves at the top show how it comes about that the expected electron emitting power depends so strongly on atomic number. In an experiment where all decay electrons are observed, the dependence on atomic number would be much more gradual than in the present experiments; however, only those electrons are considered here which come out between 0.75 microsecond and 8.75 microseconds after the time of arrival of the meson.

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[6] W. H. Bliss, Electronics 20, 126 (1947).

[7] The data for sulfur in the interval 0.5 to 0.75 μsec. are listed in Table II but are not used in the subsequent analysis.

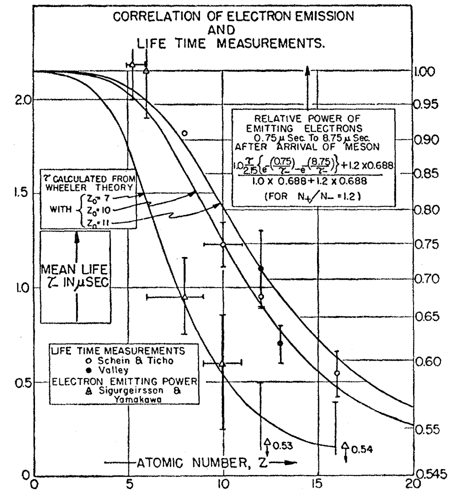

FIG. 2. Correlation of relative electron emitting power as measured here with observations on the mean lifetime, τ, of negative mesons by Valley and by Schein and Ticho. The expected correlation between the two quantities (relation between vertical scales at left and right) is computed using (1) the experimental figure, 1.2, of Hughes for ratio of positives and negatives at sea level, and (2) the fact that our experiments judge electron emitting power on the basis of the particles emitted 0.75 μsec. to 8.75 μsec. after the arrival of the meson. Since our measurements are intrinsically *relative* measurements, it should be borne in mind that all the points marked by triangles are subject to multiplication or division by a constant factor, not shown by the indicated uncertainties. The curves are calculated from Wheeler's fourth power law of meson absorption probability using, however, instead of the actual value of Z^4 the values given by him in the following paper which make allowance for the finite extension of the nucleus. The constant Z_0 represents the nuclear charge of that idealized nucleus for which natural decay and the charge exchange reaction of the meson with the nucleus compete on equal terms. Our own measurements indicate a value of Z_0 of the order of magnitude of 10, while the more recent direct lifetime measurements of other observers indicate $Z_0=10$ with an uncertainty probably less than one charge unit.

Counter tray *IV* consists of 11 counters in parallel and is used to show whether or not the meson was stopped in the moderator. If *IV* gives an impulse at the same time that a time delay is recorded in *III*, a mark is made on the time recording strip to indicate that the event in question is a spurious delay. The number of spurious delays when *IV* does go off is used later as a basis for calculating the number of spurious delays in the cases of more interest, where *IV* does not go off.

The counters in trays *I*, *II*, and *III* are of $\frac{1}{32}$-in. copper tubing with an outer diameter of 1″. Their sensitive length is about 12″. The counters in *IV* are of brass tubing of the same diameter with a sensitive length of about 15.5″. The moderator measures 2″×4″×16″.

III. PROCEDURE

On the apparatus as just described counts were recorded for the periods of time and for the coincidence arrangements which are recorded in Table I. The counting rates which are starred in Table I are those for which the pulse from *III* is delayed with respect to $I\times II$ by an amount between 0.75 μsec. and 15.75 μsec. Of course for each such count the actual value of the delay was recorded, as the basis for the decay curves later to be constructed.

The counting rates remained constant to within a few percent throughout the experiment with the exception of the counts in *IV*. Occasionally as many as three of the counters in *IV* were not operating resulting in a drop of about 30 percent in its counting rate. The efficiency of counter tray *IV* was tested at frequent intervals by comparing the number of coincidences $(I\times II)$ and $(I\times II\times IV)$ during each run. When all the counters in *IV* operate, about 16 percent of the particles going through *I* and *II* pass *IV* without being recorded. Most of these misses are due to particles passing over the sides and beyond the ends of tray *IV*. We use a $\langle\ \rangle$ with the symbol for a counter tray to indicate events in which it is not triggered off, and a cross to indicate coincidences.

IV. ANALYSIS OF SULFUR DATA

Table II lists the delayed counts observed (a) when a sulfur moderator was used, (b) when no moderator was present (background). To determine the decay curve of mesons stopped in sulfur and the electron emitting power per stopped meson, we have primarily to consider the number of counts of the type $I\times II\times III_{\text{delay}}\times\langle IV\rangle$ when the moderator was present. However, the counts listed in this column comprise not only (a) the true delays of interest but also (b) the intrinsic lags caused by an occasional slow collection of ions from counter tray *III* and which were not detected by counter tray *IV*, (c) delays produced via passage of one particle through $I\times II$ and another and independent particle which by chance goes through *III* at a random later time without striking *IV*, (d) true delays due to decay of mesons stopped in apparatus material (i.e., counter walls, supports, etc.).

An approximate division of the observed counts into the classes of true delays, intrinsic lags, and random delays, is made in the table. This division is made not only for the case of immediate interest, but also for the cases of counts without absorber, and counts of the type $I\times II\times III_{\mathrm{delay}}\times IV$ with absorber. In fact, only by the consideration of these additional cases is one in a good position to make the division at all. Thus the number of random counts and intrinsic lags can best be determined under conditions where the true delays are relatively infrequent.

We shall now describe in more detail the basis for the breakdown in each of the four sections of the table of counting rate into parts resulting from true delays, intrinsic lags, and random counts. The data for the sulfur moderator, which was used as the standard of comparsion throughout the experiment and for which the period of observation was the longest, can be broken down into its component parts most accurately and was thus chosen for this analysis. The results of this analysis will serve to determine the electron emitting power of this particular moderator as well as to determine constants for the experiment which will be used in section *V* for the analysis of data for the other moderators where the amount of data is not as large.

As mentioned earlier, the number of random counts and intrinsic lags can best be determined under conditions where the true delays are relatively infrequent. This condition is best realized in the case where no moderator is present and in the counts of the type $I\times II\times III_{\mathrm{delay}}\times IV$ where the moderator is present. These counting rates were thus used to estimate the frequency of these events. The number of intrinsic lags is known from the work of Rossi and Nereson[8] to decrease rapidly with the magnitude of the lag and to be very small at 0.8 μsec. We find similar results in our own observations on counters used in the present experiments. Consequently we conclude that after a time as long as 2 μsec. the observed counts will be due only to true delays and random events. The counting rate data without absorber after 2 μsec. were decomposed into a linear combination of a constant background and an exponential decay curve with a mean life of 2.15 μsec. The sum of the two effects so determined was then extrapolated back to times before 2 μsec. and in each of these early $\frac{1}{4}$ μsec. intervals subtracted from the observed counting rate to find the number of intrinsic lags. The random counts, the true delays, and the intrinsic lags, determined in this way for the case of no absorber and for counts of types $I\times II\times III_{\mathrm{delay}}\times\langle IV\rangle$ and $I\times II\times III_{\mathrm{delay}}\times IV$ are given in the last two sections of Table II. The true delays obtained are due to decay electrons from mesons stopped in the apparatus material. Those of the type $I\times II\times III_{\mathrm{delay}}\times\langle IV\rangle$ are caused by mesons stopped in the counter walls, the Lucite supports, and the lead shields between counter trays *III* and *IV*. Those of the type $I\times II\times III_{\mathrm{delay}}\times IV$ are due to decay electrons from mesons stopped in the table top below the apparatus. No quantitative analysis of the geometry of the supports and counter walls was made; however it does not appear that the counting rates to be expected from this source are in disagreement with the figures quoted here. The total random delays (i.e., types $I\times II\times III_{\mathrm{delay}}\times\langle IV\rangle$ and $I\times II\times III_{\mathrm{delay}}\times IV$) can be estimated from the counting rates $I\times II-I\times II\times III$, and *III* given in Table I. The random delay counts calculated in this way is 0.13/hour in an 8-μsecond interval. The total random delay counts in an 8-μsecond interval as obtained from the decomposition of the counting rates in the third and fourth sections of Table II is 0.15/hr. which is of the same order of magnitude.

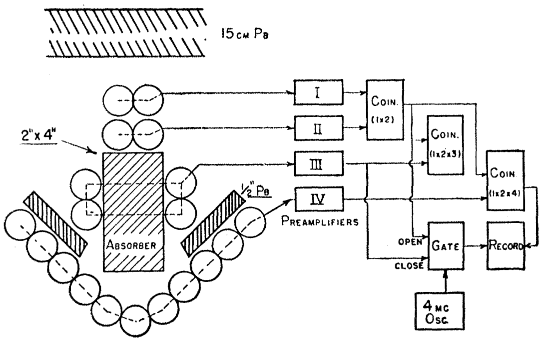

Fig. 3. Arrangement used to study electron-emitting power of stopped mesons as a function of atomic number.

The relative number of delays due to intrinsic lags of type $I\times II\times III_{\mathrm{delay}}\times\langle IV\rangle$ and $I\times II\times III_{\mathrm{delay}}\times IV$ gives an indication of the efficiency of counter tray *IV* in detecting particles that go through *I*, *II*, and *III*. The geometry of

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

TABLE I. Tabular outline of experimental procedure. The notation $<\ >$ is used to indicate an event which does not trigger the bracketed counter.

Nature of coincidence	Moderator under investigation	Standard sulfur moderator	Moderator removed ("background count")	Typical counting rates	Moderator present
$I\times II\times III$ (delay)$\times\langle IV\rangle$	Roughly 120 hr., in periods of about 24 hr. each, alternating with similar periods on sulfur moderator	Roughly 120 hr., in periods of about 24 hr. each, alternating with similar periods on moderator under investigation	Periods of roughly 48 hr. each once or twice in the course of measurements on each moderator	$2\frac{1}{2}$ to 4/hr.* $\sim\frac{1}{2}$/hr.*	YES NO
$I\times II\times III$ (delay)$\times IV$				$\sim$1/hr.* $\sim\frac{1}{3}$/hr.*	YES NO
$I\times II\times IV$				63/min.	YES
$I\times II\times III$				32/min.	YES
$I\times II$				81/min.	YES
Single counts of tray I Single counts of tray II Single counts of tray III Single counts of tray IV	5 minutes at beginning of each 24-hour run	5 minutes at beginning of each 24-hour run	5 minutes at beginning of each $\sim$48-hour run	200/min. 200/min. 330/min. 1550/min.	NO

the experimental arrangement is such that all of these particles go through IV (see Fig. 3). If counter tray IV were such that all particles going through it were detected, we should observe no delays due to intrinsic lags of the type $I\times II\times III_{\mathrm{delay}}\times\langle IV\rangle$. However as mentioned earlier some of the counters in tray IV did not operate during these experiments. The efficiency of tray IV in detecting particles that go through I, II, III, and IV obtained in this way is approximately 65 percent. The same procedure was used to decompose the counting rate of the type $I\times II\times III_{\mathrm{delay}}\times IV$ with sulfur moderator where again the number of true delays is small. The results of this decomposition are given in the second section of Table II.

Though the counts of the type $I\times II\times III_{\mathrm{delay}}\times\langle IV\rangle$ in the first section of Table II cannot be decomposed in this way since here the number of true delays is large, the results of the last three sections of Table II can be used to make this decomposition. The ratio of the random counting rate of type $I\times II\times III_{\mathrm{delay}}\times\langle IV\rangle$ to those of the type $I\times II\times III_{\mathrm{delay}}\times IV$ for the case of no moderator is approximately the same as that where the moderator is present. Thus the random counts in this section were obtained by proportion, using this ratio and the random counting rate of the type $I\times II\times III_{\mathrm{delay}}\times IV$ for the case where the moderator was present. The random counting rate is therefore $(2.3/4.4)(6.1)=3.2$. The same considerations apply to the intrinsic lags. Thus, the number of intrinsic lags in each of the intervals was obtained from those in the last three sections of Table II. The number of true delays was obtained by subtracting the random counts and the intrinsic lags estimated in this way from the counts of type $I\times II\times III_{\mathrm{delay}}\times\langle IV\rangle$. The results of this decomposition are given in the first section of Table II. The true delays in this section are due to decay electrons from mesons stopped in the sulfur moderator and to decay electrons from mesons stopped in the apparatus material which were determined from the case of no moderator and are given in the third section of Table II. By subtracting the true delays for the case of no moderator from those with the moderator present we obtain the delayed counts caused by decay electrons from mesons stopped in the sulfur moderator.

In making a comparison of the relative electron emitting powers of the moderators used, the corrected values of the delayed counts in the interval 0.75 to 8.75 μseconds were used though data were obtained for the interval 0.5 to 16.25 μseconds for the following reason. In the interval 0.5 to 0.75 μsecond the number of delays caused by intrinsic lags is quite high; however in the next interval 0.75 to 1.0 μsec. it is already low. Thus though corrections for the intrinsic lags were made it was thought advisable to leave out the first interval. Also after 8.75 μseconds the number of true delays is small compared to the random delays, and thus data after 8.75 μseconds were also discarded in making comparisons of the electron-emitting power of the various moderators. However, these data were useful in making the corrections to the observed counting rates and were used for this purpose.

The number of delays between 0.75 to 8.75 μsec. as a result of decay electrons from mesons stopped in sulfur is observed to be 1.75 per hour. The corresponding counting rate for the other moderators was obtained and compared with that obtained for sulfur in the following section.

V. ANALYSIS OF THE DATA FOR OTHER MODERATORS USED

The analysis of the data for these materials follows closely that discussed in the previous section for sulfur and the results of the previous analysis are used here whenever possible. It is thus given here in a summarized form.

Table III gives the results of this analysis and includes a comparison of the relative electron emitting power of the various substances. Row 2 gives the mean density of the moderators used. An effort was made to make the mean densities of the moderators as close to each other as possible and as high as possible. The observed number of counts in the interval 0.75 to 8.75 μsec. reduced to counts per hour are given in the third row for counts of the types $I\times II\times III_{\text{delay}}\times\langle IV\rangle$ and $I\times II\times III_{\text{delay}}\times IV$.

The true delays in counts per hour resulting from decay electrons from mesons stopped in the moderator were obtained from the observed counting rates in the following way. Since the periods of observation for these materials were shorter than that for sulfur, the number of counts of type $I\times II\times III_{\text{delay}}\times IV$ were not sufficient to make a breakdown into parts as was done for the case of sulfur. The decomposition was thus made by using the results of the analysis for the case of no moderator. The random counts and true delays caused by decay electrons from the apparatus material of both types were assumed to remain constant throughout the experiments and equal to that obtained for the case of no moderator. The data for the case of no moderator were taken intermittently throughout the experiment and thus should give a good average value. These counts reduced to counts per hour are given in Table III. The delays resulting from intrinsic lags were obtained from the observed

Table II. Delayed counts observed in the case of sulfur moderator in 459.5 hours, showing how corrections are made for intrinsic lags and random delays. For this purpose use is made of the counting rates observed in 366.4 hours of run without moderator.

	Counts with sulfur moderator, 459.5 hours								Counts with moderator removed, 366.4 hours							
	$I\times II\times III_{\text{delay}}\times\langle IV\rangle$				$I\times II\times III_{\text{delay}}\times IV$				$I\times II\times III_{\text{delay}}\times\langle IV\rangle$				$I\times II\times III_{\text{delay}}\times IV$			
		Decomposition into				Decomposition into				Decomposition into				Decomposition into		
Interval in μsec. between I $\times II$ and III	Observed counts uncorrected	Random counts	True delays	Intrinsic lags	Observed counts uncorrected	Random counts	True delays	Intrinsic lags	Observed counts uncorrected	Random counts	True delays	Intrinsic lags	Observed counts uncorrected	Random counts	True delays	Intrinsic lags
0.5 to 0.75	172	0.8	127	∼45	101	1.5	13.1	∼86	50	0.6	15.2	∼34	72	1.1	5.7	∼65
0.75 to 1.00	158	0.8	138	∼20	42	1.5	11.6	∼29	27	0.6	13.5	∼13	24	1.1	5.0	∼18
1.00 to 1.25	89	0.8	83	∼ 6	12	1.5	10.4	∼ 8	15	0.6	12.0	∼ 4	12	1.1	4.5	∼ 6
1.25 to 1.50	100	0.8	98	∼ 2	10	1.5	9.2	∼ 3	14	0.6	9.0	∼ 1	7	1.1	3.4	∼ 2
1.50 to 1.75	76 } 228	3.2	225	0.0	11 } 30	6.1	27.4	0.0	10 } 36	2.3	31.8	0.0	6 } 19	4.4	11.9	0.0
1.75 to 2.00	62				7				14				3			
2.00 to 2.25	49				9				6				4			
2.25 to 2.50	41				3				6				6			
2.50 to 2.75	45 } 156	3.2	153	0.0	14 } 32	6.1	17.3	0.0	8 } 22	2.3	20.0	0.0	1 } 10	4.4	7.4	0.0
2.75 to 3.00	43				8				5				0			
3.00 to 3.25	31				6				5				4			
3.25 to 3.50	37				4				4				5			
3.50 to 3.75	24 } 91	3.2	88	0.0	3 } 18	6.1	10.7	0.0	3 } 14	2.3	12.4	0.0	4 } 9	4.4	4.7	0.0
3.75 to 4.00	26				7				3				3			
4.00 to 4.25	21				6				5				1			
4.25 to 4.50	20				2				3				1			
4.5 to 5.5	57	3.2	54	0.0	12	6.1	6.8	0.0	10	2.3	7.9	0.0	4	4.4	2.9	0.0
5.5 to 6.5	48	3.2	45	0.0	10	6.1	4.2	0.0	4	2.3	4.8	0.0	7	4.4	1.8	0.0
6.5 to 7.5	31	3.2	28	0.0	7	6.1	2.7	0.0	10	2.3	3.1	0.0	8	4.4	1.2	0.0
7.5 to 8.5	13	3.2	10	0.0	9	6.1	1.7	0.0	5	2.3	2.0	0.0	5	4.4	0.7	0.0
8.5 to 9.5	15	3.2	12	0.0	9	6.1	1.0	0.0	4	2.3	1.2	0.0	9	4.4	0.4	0.0
9.5 to 10.5	9	3.2	6	0.0	9	6.1	0.7	0.0	4	2.3	0.7	0.0	5	4.4	0.3	0.0
10.5 to 11.5	7	3.2	4	0.0	8	6.1	0.4	0.0	3	2.3	0.5	0.0	9	4.4	0.2	0.0
11.5 to 12.5	5	3.2	2	0.0	5	6.1	0.3	0.0	4	2.3	0.3	0.0	2	4.4	0.1	0.0
12.5 to 13.5	8	3.2	5	0.0	7	6.1	0.2	0.0	0	2.3	0.2	0.0	3	4.4	0.1	0.0
13.5 to 14.5	1	3.2 }	0	0.0	5	6.1	0.1	0.0	4	2.3	0.1	0.0	2	4.4	0.1	0.0
14.5 to 15.5	6	3.2			3	6.1	0.1	0.0	4	2.3	0.1	0.0	6	4.4	0.1	0.0
15·5 to 16.25	2	3.2			3	6.1	0.1	0.0	1	2.3	0.0	0.0	1	4.4	0.1	0.0

TABLE III. Analysis of counting rates to determine the relative electron emitting power of all materials studied. All counts dealt with here refer to delay times between 0.75 μsec. and 8.75 μsec. The following results from Table II are used.

(1) Case of moderator present: apparent delays, actually a result of random counts, per hour in the interval 0.75 to 8.75 μsec. after arrival of meson: 0.06 count of type $I\times II\times III_{\text{delay}}\times\langle IV\rangle$, 0.12 count of type $I\times II\times III_{\text{delay}}\times IV$.

(2) Case where moderator is removed: true delays per hour in the same interval as a result of decay electrons from apparatus material (i.e., counter walls, lucite supports, etc.); 0.25 count of type $I\times II\times III_{\text{delay}}\times\langle IV\rangle$, 0.12 count of type $I\times II\times III_{\text{delay}}\times IV$.

Moderator		Be	B_4C	C	Teflon	NaF	Mg	S
Mean density of moderator (g/cm^3)		1.85	1.40	1.64	2.12	1.58	1.78	1.96
Type of Counts								
$I\times II\times III_{\text{delay}}\times\langle IV\rangle$	No. of counts	449	367	469	469	272	206	See Table II
	Per. of obs.	132.9 hr.	128 hr.	133.1 hr.	163.5 hr.	117.3 hr.	103.5 hr.	
	Counting rate	3.38/hr.	2.87/hr.	3.52/hr.	2.87/hr.	2.32/hr.	1.99/hr.	
$I\times II\times III_{\text{delay}}\times IV$	No. of counts	74	28	61	73	27	41	See Table II
	Per. of obs.	132.9 hr.	128 hr.	133.1 hr.	163.5 hr.	117.8 hr.	103.5 hr.	
	Counting rate	0.56/hr.	0.22/hr.	0.46/hr.	0.45/hr.	0.23/hr.	0.04/hr.	
Apparent delays of the type $I\times II\times III_{\text{delay}}\times IV$, actually caused by intrinsic lags, obtained by subtracting from preceding row the random counts, 0.12/hr. and the true delays without moderator 0.12/hr.		0.32	$\sim$0	0.22	0.21	$\sim$0	0.16	See Table II
Apparent delays of the type $I\times II\times III_{\text{delay}}\times\langle IV\rangle$, actually caused by intrinsic lags, determined by proportion from numbers in preceding row. Constant of proportionality 0.57 determined from run with no moderator (see text)		0.18	$\sim$0	0.12	0.11	$\sim$0	0.11	See Table II
Delays of the type $I\times II\times III_{\text{delay}}\times\langle IV\rangle$ caused by mesons actually decaying in moderator, obtained from third row by subtracting random counts (0.06/hr.), intrinsic lags (preceding row) and true delays due to mesons stopped in apparatus material (0.25/hr.)		2.89	2.56	3.08	2.45	2.0	1.59	From Table II 1.75
Range in cm of 30-Mev mesons		3.28	4.20	3.42	2.87	3.98	3.48	3.22
Product of last two rows. A quantity directly proportional to the number of electrons per stopped meson		9.45	10.75	10.5	7.03	6.25	5.53	5.63
Preceding row referred to sulfur as standard of comparison		1.68±0.11	1.91±0.14	1.86±0.12	1.25±0.09	1.11±0.09	0.98±0.10	[1.00]
Same, arbitrarily normalized for plotting		0.91±0.06	1.03±0.08	1.0 ±0.07	0.68±0.05	0.60±0.05	0.53±0.05	0.54±0.03

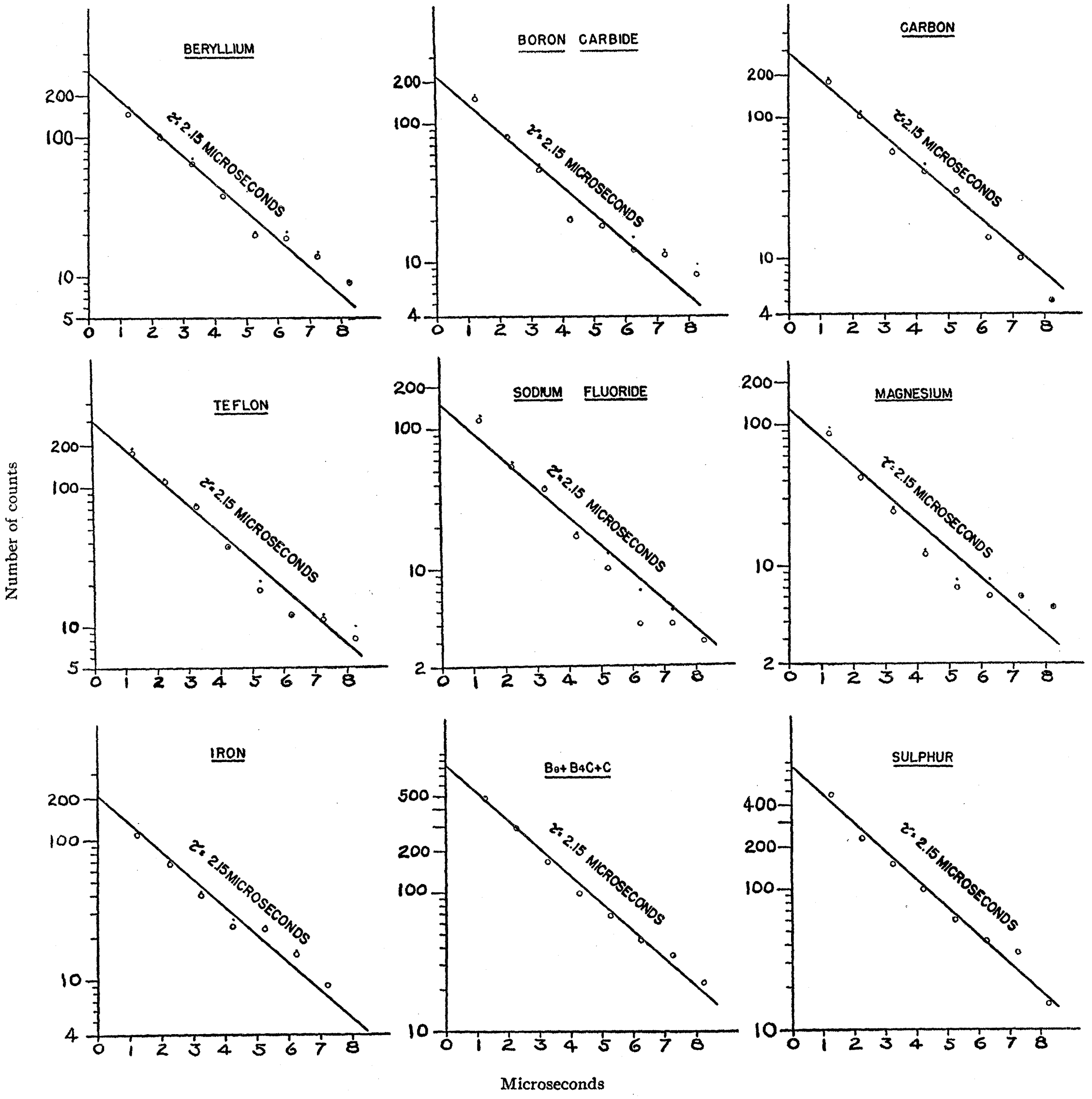

FIG. 4. *Differential* decay curves for the natural sea-level mixture of positive and negative mesons. Dots and circles represent original and corrected counts, respectively. Especially many counts were accumulated for sulfur, the standard of reference in these measurements. The combined decay curve for light elements, next to the sulfur curve, shows no observable difference in effective mean life as compared to sulfur. This result is in accord with theoretical expectations for an experiment where no magnetic separation is employed and where all data are excluded for delay times less than 0.75 μsec. (Fig. 5).

counting rates of type $I\times II\times III_{\text{delay}}\times IV$ by subtracting the corresponding random and true delay counts. The delayed counting rates resulting from intrinsic lags obtained in this way are given in row 4 of the table. From the results and discussion in the previous section, the number of these counts that occur in the counts of the type $I\times II\times III_{\text{delay}}\times\langle IV\rangle$, due to the inefficiency of tray IV to detect particles striking I, II, and III, can be obtained by using the value for the efficiency of tray IV in detecting these events which was estimated in the previous section for the case of no moderator. The efficiency determined was approximately 65 percent so that about 0.57 of the delays caused by intrinsic lags of type $I\times II\times III_{\text{delay}}\times IV$ occur as type $I\times II$

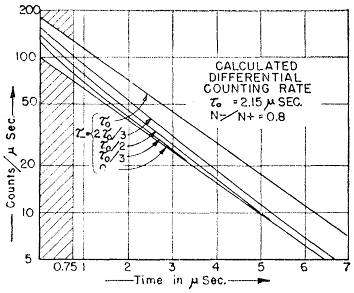

FIG. 5. Expected form of decay curves for normal sea level mixture of positive and negative mesons. This set of curves differs from those given by Schein and Ticho only through the fact that theirs give the total count expected up to a given time whereas these give the differential rate of counting. It is seen that measurements such as ours which record rates of counting beginning only 0.75 μsec. after arrival of the meson, will be expected to show no significant departure from the normal 2.15 μsec. mean life, in accordance with the results reported in Fig. 4.

$\times III_{\text{delay}}\times\langle IV\rangle$. These delays are listed in row 5 of Table III. The true delays due to decay electrons from mesons stopped in the absorber were obtained by subtracting from the observed counting rates of types $I\times II\times III_{\text{delay}}\times\langle IV\rangle$ in row 3 the random delays and true delays caused by decay electrons from the apparatus material, and the corresponding delays due to intrinsic lags given in row 5. These corrected counting rates are given in row 6 of the table. The corrected counting rate for sulfur obtained in the previous section is included. In order to make a comparison of the electron emitting power of the various moderators used, corrections must be made for the difference in densities of the moderators and the fact that the range of mesons depends on the atomic number of the absorbing medium. The range of mesons in the various moderators obtained from the range energy curves of Wheeler and Ladenberg[9] are given in row 7 of the table. Thirty Mev was chosen as approximately the average energy of mesons stopped by the moderator. The product of these numbers and those in the previous row give quantities that are directly proportional to the number of electrons emitted per stopped meson. The following row gives these same quantities normalized to unity for sulfur with their mean statistical deviations. The last row gives these same quantities arbitrarily normalized for plotting. These values are plotted in Fig. 1 and are compared with the electron emitting power calculated from Wheeler's Z^4_{eff} law for decay electrons in the interval 0.75 to 8.75 μsec. It is to be noted that the experimental values are relative and can be multiplied by an arbitrary constant. Thus only the relative values are significant in making a comparison with the theoretical curves. Radiative losses by decay electrons in moderators of high atomic number can somewhat reduce the number of delayed coincidences. No corrections for such an effect were made in the present paper.

The differential decay curves obtained from these measurements are plotted in Fig. 4. Both the observed and corrected values are included. Only the values in the interval from 0.75 to 8.75 μseconds are shown.

The conclusions of these experiments are listed in Section I of this paper.

VI. ACKNOWLEDGMENTS

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[9] J. A. Wheeler and R. Ladenberg, Phys. Rev. 60, 754 (1941).