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MEASUREMENT OF THE POSITIVE PI-MESON LIFETIME

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MEASUREMENT OF THE POSITIVE π -MESON LIFETIME

Clyde E. Wiegand

October 16, 1950

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MEASUREMENT OF THE POSITIVE π -MESON LIFETIME

Clyde E. Wiegand

INTRODUCTION

The first evidence of the decay of a heavy (π) meson into a lighter (μ) meson was tracks in a photographic emulsion which had been exposed to cosmic rays by Lattes, Muirhead, Occhialini and Powell.⁽¹⁾ From the length of time the heavy meson spent in the emulsion they set a lower limit on the lifetime as 10^{-11} sec.

Later Lattes working with π -mesons produced artificially in the Berkeley 184-inch cyclotron was able to establish an experimental lower limit of 5×10^{-9} sec. for the lifetime. The first direct measurement of the π -meson lifetime was made by Richardson.⁽²⁾ His method was to measure the fraction of negative π -mesons which survived various times of flight in the cyclotron vacuum tank. He detected the mesons by photographic plates and reported the mean lifetime of $1.11 \pm \frac{0.45}{0.35} \times 10^{-8}$ sec. Later Martinelli and Panofsky⁽³⁾ using a technique similar to that of Richardson measured the mean lifetime of positive π -mesons. They found τ equals $1.97 \pm \frac{0.21}{0.25} \times 10^{-8}$ sec.

In the light of recent developments in electronic techniques it was natural to plan experiments to determine the lifetime of the π -mesons by means of electronic detectors because of the expected improvement in accuracy over previous methods. A classic example of electronic

(1) C.M.G. Lattes, Muirhead, Occhialini and Powell, Nature 159, 694 (1947), 160, 486 (1947)

(2) J. Richardson, Phys. Rev. 74, 1720 (1948)

(3) E.A. Martinelli and W.K.H. Panofsky, Phys. Rev. 77, 465 (1950)

technique for the measurement of a mean lifetime in the microsecond region is that of F. Rasetti's⁽⁴⁾ work on "slow mesons" which are now identified as μ -mesons.

The recent advances in the field of electronic detectors which have made it possible to determine radioactivity decay times of the order of 10^{-8} sec. are the following: the discovery that some organic phosphors emit their phosphorescent radiation in a mean lifetime of about 10^{-8} sec.⁽⁵⁾; the development of multiplier phototubes which are able to detect relatively few photons by means of photoelectrons and to multiply the number of such photoelectrons by secondary emission by a factor of 10^6 so that they become electrical pulses which do not require high gain amplifiers; the development of pulse amplifiers of medium gain which can amplify photomultiplier tube outputs to a level suitable for operation of cathode ray oscillographs and other pulse recording devices.

EXPERIMENTAL METHOD

The presently described work utilized the 322 Mev (maximum) x-ray beam of the Berkeley synchrotron to produce π -mesons in a target of polyethylene. Fig. 1 is a diagram of the arrangement of the apparatus. The x-ray beam was collimated by lead shielding to produce a beam 1 inch in diameter incident upon the polyethylene target which was in size and shape a 2-inch cube. The detectors consisted of two crystals of trans-stilbene arranged to form a counter "telescope" at right angles to the beam. The phosphorescent radiation caused by an ionizing particle which passed through either of the crystals was detected by multiplier phototubes associated with each crystal. The entire apparatus was surrounded by lead shielding 6 to 8 inches thick. Each crystal measured 4.5 x 4.1 cm and was

(4) F. Rasetti, Phys. Rev. 59, 706 (1941) 60, 198 (1941)

(5) R. Pringle, Nature 166, 11, (1950)

1.8 cm thick. An aluminum absorber 1 inch thick was placed between the target and the detectors in order to reduce the energy of the emitted mesons. This had the effect of increasing the probability that a meson would stop in the crystal detector.

Let us consider some possible sequences in time of pulses from the two detectors for various particles emitted by the target. First suppose an electron or meson passed through both crystals. We would then find a pulse occurring in each detector simultaneously (within 3×10^{-10} sec.). Next suppose the target emits a positive π -meson which has a range such that it passes through the crystal nearer the target and stops inside the second crystal. Again we would find pulses occurring practically simultaneously in each detector because the meson would come to rest in about 1.5×10^{-10} sec. in the second crystal. In addition to the pulse from the stopping of the positive π -meson in the second crystal, there would be a pulse made by the μ -meson emitted upon decay of the π -meson. The average time between these two events will be the mean lifetime of the π -meson. The range of the μ -meson is about 0.2 cm in trans-stilbene and this is small compared to the dimensions of the crystal. Therefore if the detector is equally sensitive over the volume of the crystal, the μ -meson pulses should be of about equal height if edge effects are neglected. One more pulse should be observed in the chain of events started by the stoppage of a positive π -meson in the second crystal. This would be a pulse arising from the decay of the μ -meson into a positive electron. The third event would occur on the average 2.15×10^{-6} sec. after the decay of the π -meson, 2.15×10^{-6} sec. being the mean lifetime of the positive μ -meson. The pulse due to the positron from the decay of the μ -meson cannot always be detected because the range of the positron is

longer than the dimensions of the crystal and consequently too much of its ionization energy may be spent outside the crystal.

The object of this experiment was to determine the mean lifetime of positive π -mesons by measuring the time intervals between the stopping of π -mesons and the emission of μ -mesons. In order to be certain that the observed pulses were due only to π -mesons, the μ -decay positrons were detected and recorded by an apparatus developed by Steinberger.⁽⁶⁾ The time intervals corresponding to the lifetime of the π -mesons were measured by recording photographically the pulses from the second crystal detector displayed on the screen of a cathode-ray oscillograph.

APPARATUS

A block diagram of the electronic apparatus is presented in Fig. 2. The design of the electronic components was for the most part based upon standard techniques employing resistance-capacitance coupling and high trans-conductance miniature tubes to obtain sufficiently rapid response in the coincidence and gate-forming circuits. However, sufficient resolution of the π to μ -decay pulses requires a vertical deflection amplifier capable of producing pulses which have a time of rise of 10^{-8} sec. or less. The deflection amplifier used in this experiment made use of the traveling wave concept and its design was based upon principles discussed by Ginzton, Hewlett, Jasberg and Noe⁽⁷⁾ in their paper on distributed amplification. The time of rise of the oscillograph deflection system was about 5×10^{-9} sec. A schematic diagram of the vertical deflection amplifier and associated apparatus is given in Fig. 3.

Let us review the electronic events due to the detection of a π - μ decay: If a meson passed through crystal number 1 and stopped in

(6) J. Steinberger and A.S. Bishop, Phys. Rev. 78, 493 (1950)

(7) Ginzton, Hewlett, Jasberg and Noe, Proc. I.R.E. 36, 956 (1948)

number 2 and the pulses were accepted by discriminators A and B, there was produced at the output of coincidence number 1 a pulse which started the sweep and intensifying circuits of the oscillograph and at the same time initiated a circuit which opened a series of four delayed gates beginning 0.5μ sec. later. The length of the delayed gates was 2×10^{-6} sec. On account of its limited resolution coincidence number 1 treated the two pulses from the stopping of the π -meson and the emission of the μ -meson as one event. The output of detector number 2 was also connected to another discriminator, C, biased to accept μ -meson decay positron pulses. If a particular pulse was accepted by discriminator C it was fed to the delayed gate circuit and if a gate were open the pulse was recorded by the register associated with the open gate. When a pulse was recorded in the first delayed gate, an additional circuit was actuated and caused a small neon lamp to flash momentarily. The neon lamp was placed near the face of the oscillograph tube and in the field of view of the recording camera. Its flash would thus produce a dot on the film at the end of the sweep trace. The dot appearing at the end of the trace would then indicate that the pulse from the μ decay positron had been detected. A third connection to detector number 2 was made to a section of 125 ohms impedance RG 63/U coaxial cable 125 meters long and thence to the distributed amplifier the output of which was connected as directly as possible to the vertical deflection plates of the oscillograph. The purpose of the long cable was to delay the pulse about 0.5 microsecond in order to allow the oscillograph sweep and intensifier circuits to become operative. The sweep duration was 0.8×10^{-6} sec. The oscillograph trace thus displayed the pulses which occurred in detector number 2 during the first time interval of 0.8×10^{-6} sec. after the passage of a particle through detector number 1

and into or through number 2.

The particular oscillograph used in this experiment was a modified Tektronix type 511 AD. The modification consisted in replacing the original type 5CP1A cathode ray tube by a type 5XP11 and applying to it a total accelerating voltage of 14 kilovolts. The recording camera was a General Radio oscillograph recorder with an f1.5 lens. Eastman Linagraph Panchromatic film was used and passed continuously through the camera at such a rate that the traces were conveniently spaced. Fig. 4 is a reproduction of a typical trace. The film was developed in Eastman D-19 developer with intermittent agitation for a period of 20 minutes at a temperature of 70° F.

SWEEP CALIBRATION

The sweep speed of the oscillograph was calibrated by applying a sine wave voltage of known frequency to the vertical deflection plates. The sweep speed is then directly determined by measuring the length of a cycle of the recorded sine wave. Such calibrations were made several times during the course of the experiment. The standard frequency source was a General Radio type 605-B signal generator accurately calibrated to within ± 0.3 percent. Also we allowed a slight amount of extraneous pick up from the synchrotron radiofrequency system which provided a practically continuous calibration by its presence on the pulse base line. The frequency of the synchrotron was constant and by a different signal generator was found to be 47.34 ± 0.02 megacycles per second. This measurement of the sweep speed checked with the calibration by the General Radio signal generator. The sweep speed was practically linear over the range of the recorded π - μ lifetimes and amounted to 1.3×10^{-8} sec. mm⁻¹ at the screen of the cathode ray tube.

ACCUMULATION OF DATA

With the apparatus in the synchrotron x-ray beam as indicated in Fig. 1 the beam intensity was adjusted by trial to give a reasonable rate of traces exhibiting π - μ decay pulses and at the same time a reasonably low background of spurious traces. The description of a typical run is as follows: During a $1\frac{1}{2}$ hour exposure the standard length of 100 feet of film was run through the camera. There were recorded upon this film 5232 traces of which 168 bore the neon lamp flash marker.

A microfilm reader was used to examine the processed film. Images of the traces were projected onto a piece of graph paper upon which the distance between two pulses could easily be determined to within 1 mm. With the particular camera and projector arrangement employed, 1 mm on the projector screen represented 0.362×10^{-8} sec.

The distances between pairs of pulses was interpreted as indicated by Fig. 5. Points halfway up the leading slopes were determined and the distance between pulses was taken to be the distance between the projections upon the base line of these two points.

All double pulses marked by the flash were included in the tabulation of the data. Only in a very few instances was it questionable that a pulse-like disturbance on the baseline was due to a μ -meson. The heights of the μ -meson pulses were fairly uniform as is indicated by a plot of the number of pulses versus their height in Fig. 6. Considering all the traces marked by the neon flash bulb it was not possible in every instance to observe two distinct pulses. This was interpreted as being due to π -meson decays occurring within the resolving time of the system and consequently the stopping of the π -meson and emission of the μ -meson appearing as one pulse. The treatment of such unresolved decays will be discussed later.

RESULTS

During the course of the experiment a total of 1419 separate traces marked with the neon flash bulb were accumulated. A total of 691 of the marked traces exhibited two clearly separated pulses between which the distance could be measured, and the remainder were unresolved. The distances between the pairs of pulses were tabulated to the nearest millimeter on the projector screen which represented a time interval of 0.362×10^{-8} sec. A histogram of the number of pulses which occurred with various time separations is presented in Fig. 7.

An integral representation of the same data is given in Fig. 8 in which the total number of pulses occurring after a certain time is plotted as a function of this time upon semilogarithmic paper. This number is given by $N(t) = N_0 e^{-\lambda t}$ where N_0 is the total number of recorded traces due to π -mesons stopping in the detector and λ is the meson decay constant. A preliminary value of the mean lifetime $\tau = 1/\lambda$ is the length of time for $N(t)$ to diminish by the factor $1/e$. The determination of the point in the first time interval and corrections to τ will be discussed later.

In Fig. 9 the data are shown in differential form where the logarithm of ΔN , the number of pulses occurring in the constant time interval $4 \times 0.362 \times 10^{-8}$ sec. is plotted versus time. Again τ is the time for ΔN to diminish by the factor $1/e$ and by inspection of the curve is seen to amount to about 2.6×10^{-8} sec.

a. Analysis of differential curve.

Inspection of the histogram Fig. 7 and the integral curve Fig. 8 reveals that apparently all of the π - μ decay pulses were resolved after $6 \times 0.362 \times 10^{-8}$ sec. Therefore on the differential curve of Fig. 9 are plotted the number of pulses separated by $6 \times 0.362 \times 10^{-8}$ sec. and longer

times. The time interval was chosen to be $4 \times 0.362 \times 10^{-8}$ sec. in order to include enough pulses in the time intervals to afford reasonable statistical accuracy. All pulses from $6 \times 0.362 \times 10^{-8}$ sec. through $70 \times 0.362 \times 10^{-8}$ sec. were included in the data.

The mean lifetime is given by

$$\tau = \frac{\sum_i N_i t_i}{\sum_i N_i}$$

where N_i is the number of π -mesons which decay in the i th time interval and t_i is the time from an arbitrary origin to the center of the i th interval. Since not all of the pulses were resolved until after the 6th interval of 0.362×10^{-8} sec. we have chosen as time 0 the center of the 6th interval. We have then

$$\tau = \frac{\sum_{i=6}^{70} N_i \times t_i}{\sum_{i=6}^{70} N_i} = \frac{4049 \times 0.362 \times 10^{-8}}{554}$$

$$\tau = 2.65 \times 10^{-8} \text{ sec.}$$

The statistical error in the result for τ is obtained by a method pointed out by Peierls. (8) The percentage error in τ is given simply by $1/\sqrt{N}$ where N is the total number of measured pulses (554).

$$\tau = (2.65 \pm 0.11) \times 10^{-8} \text{ sec.}$$

A correction for a systematic error and a discussion of the reliability of the measurements will be given later.

b. Analysis of the integral curve

The integral representation of the data allows us to make use of the unresolved pulses in the first few time intervals providing we know the total number of mesons which stopped in the detector. This procedure gives a point of high statistical accuracy and is important in determining

(8) R. Peierls. Proc. of Royal Soc. 149, 467 (1935)

the slope of the decay line. However, it may be reduced in effectiveness by the uncertainty of the necessary corrections for background.

Of the 1419 recorded traces marked by the neon bulb 691 showed two resolvable pulses leaving 728 unresolved single appearing pulses. However, not all the unresolved pulses were due to π -mesons stopped in the detector because there was a background of spurious pulses which could fall within the delayed gate time, initiate the flash bulb and thus give false impressions of arising from μ -meson decay positrons. Another source of single background pulses originated from the decay of π -mesons while in flight from the polyethylene target to the detectors. Such events could lead to μ -mesons coming to rest in the detector, making single pulses, and then their decay positrons activating the neon bulb flasher.

An estimate of the number of spurious unresolved pulses can be made as follows: If all the pulses arriving at the delayed gates were due to positrons from μ -meson decay, they should accumulate in the four gates according to the law $N_i = N(0) e^{-\lambda_\mu t_i}$ ($i = 1, 2, 3, 4$) where t_i is the time at the center of the gate. A departure from this law can be attributed to the background. If we assume $\lambda_\mu = 4.65 \times 10^5 \text{ sec.}^{-1}$ ($\tau_\mu = 2.15 \times 10^{-6} \text{ sec.}$) and attempt to fit the expected curve to the experimental data, we find that a background of about 5 percent of the total number of pulses must be subtracted.

Another calculation of the background pulses falling into the delayed gates and flashing the neon bulb can be made from the auxiliary counters indicated on the block diagram of Fig. 2. The number of gates made was equal to the number of pulses in coincidence accepted by discriminators A and B and registered in scaler AB. The number of pulses

which could fall into a delayed gate was the number accepted by discriminator C and registered in scaler C. Then if τ was the time in seconds that a gate remained open each time it was made and T was the time during which the number of counts N_{AB} and N_C were accumulated, the number expected to randomly fall into a gate is given by

$$N \text{ accid} = \frac{N_{AB} \times N_C \times \tau}{T \times F}$$

Where F is the fraction of time the synchrotron beam was actually on and is sometimes referred to as the duty cycle. The beam pulses came at a rate of 6 per second and had a duration of 2×10^{-3} sec. Hence

$$F = 6 \times 2 \times 10^{-3}$$

A typical run lasted 87 minutes during which 4,217 pulses were received in scaler AB and 73,820 in scaler C. τ was 2×10^{-6} sec. for each of the four delayed gates. Putting these values in the formula for the number of accidentals

$$N \text{ accid} = \frac{4,217 \times 10^3 \times 7,382 \times 10^4 \times 2 \times 10^{-6}}{87 \times 60 \times 12 \times 10^{-3}} = 9.94$$

During this run 160 pulses were registered in the first delayed gate. If then 10 of these were background as we have just computed 10/160 or about 6 percent of the pulses were accidental and this agrees within statistical accuracy with the previously estimated value. The average background of spurious unresolved pulses for the entire experiment came to 7 percent of the total number of neon flash bulb marked pulses.

The second correction needed to establish the total number of stopped π -mesons is obtained by evaluating the fraction of π -mesons which decayed in flight from the target to the detector. The kinetic

energy of the emitted π -mesons lies in the region of 60 Mev and their rest energy m_0c^2 is about 140 Mev. Then $v/c = 0.72$ where v is the velocity of the meson and c is the velocity of light. Since the energy of the emitted mesons is not constant, it will be sufficient to consider the velocity constant during the flight. The probability that a meson decay while traversing the distance $d = 20$ cm from the target to the detector is

$$\frac{\sqrt{1-v^2/c^2}}{\tau} \frac{d}{v} = \frac{0.7 \times 20}{2.6 \times 10^{-8} \times 0.72 \times 3 \times 10^{10}} = 0.025$$

where τ is the approximate mean lifetime.

We have finally a background of about 10 percent to subtract from the total number of recorded traces marked by the neon flasher. This leaves 1277 pulses for the first point on the integral curve.

The data of the integral representation can be conveniently analyzed by calculating the average lifetime of the unresolved pulses and combining this point with the differential curve. The average lifetime τ' of the unresolved pulses can be expressed as follows:

$$\tau' = \frac{\int_0^T \lambda e^{-t/\tau} t dt}{\int_0^T \lambda e^{-t/\tau} dt} = \tau \left[1 + \frac{T/\tau}{1 - e^{-T/\tau}} \right]$$

where $\tau = 2.65 \times 10^{-8}$ sec. is the mean lifetime obtained from the differential curve and the time T for the pulses to be fully resolved is $6 \times 0.362 \times 10^{-8}$ sec. Then

$$T/\tau = \frac{6 \times 0.362 \times 10^{-8}}{2.65 \times 10^{-8}} = 0.82$$

$$\tau' = 2.65 \times 10^{-8} \left[1 + \frac{0.82}{1 - e^{-0.82}} \right] = 0.91 \times 10^{-8} \text{ sec.}$$

To combine this information with the differential data we subtract

the 554 resolved pulses used in the differential curve from the total of 1277 leaving 723 unresolved pulses N_s . We must insert another term, $N_i \times 6 \times 0.362 \times 10^{-8}$ sec. in the numerator of the mean lifetime relation so that the origins of the time scales will coincide. Finally the mean lifetime including the unresolved pulses is given by

$$\tau = \frac{\sum N_i t_i + 6 \times 0.362 \times 10^{-8} \times N_i}{\sum N_i + N_s}$$

$$\tau = \frac{4049 \times 0.362 \times 10^{-8} + 6 \times 0.362 \times 10^{-8} \times 554 + 723 \times 0.91 \times 10^{-8}}{554 + 723}$$

$$\tau = 2.605 \times 10^{-8} \text{ sec.}$$

In the above analysis a total of 1277 measurements are involved so that if we apply Peierls' method of determining the error we find a standard deviation of ± 2.8 percent, or

$$\tau = (2.605 \pm 0.07) \times 10^{-8} \text{ sec.}$$

The actual standard deviation is somewhat larger because we do not know the exact time at which the unresolved pulses occurred whereas in Peierls' analysis it is assumed that the time at which each pulse occurred is known exactly. It is easy, however, to see that this addition to the standard deviation under our experimental conditions is small compared to the term $1/\sqrt{N}$.

SYSTEMATIC ERROR

A systematic error which caused an apparent lengthening of the mean lifetime arose as follows: The gate which allowed the μ -meson decay positron to be detected was initiated by the stopping of π -mesons whereas to be consistent in allowing a constant fraction of decay positron

pulses to fall within it, the gate should have been initiated by the μ -meson pulses. Consequently the longer a π -meson lived in the detector, the higher was the probability that its μ -meson decay positron pulse would fall within the delayed gate and actuate the neon flash circuit. The magnitude of this effect can be calculated by establishing zero time as the time when a π -meson stopped in the detector, t_1 the time the π -meson decayed, t_2 the time the gate opened and t_3 the time the gate closed. The probability that a μ -decay positron falls within the gate is

$$P = \int_{t_2}^{t_3} \lambda_{\mu} e^{-\lambda_{\mu}(t-t_1)} dt = e^{-\lambda_{\mu}(t_2-t_1)} - e^{-\lambda_{\mu}(t_3-t_1)}$$

The mean π -meson lifetime which was actually measured can be expressed by

$$\tau_{\pi} = \frac{\int_0^{\infty} P(t_1) \lambda_{\pi} t_1 e^{-\lambda_{\pi} t_1} dt_1}{\int_0^{\infty} P(t_1) \lambda_{\pi} e^{-\lambda_{\pi} t_1} dt_1} = \frac{\int_0^{\infty} t_1 e^{-(\lambda_{\pi}-\lambda_{\mu})t_1} (e^{-\lambda_{\mu} t_2} - e^{-\lambda_{\mu} t_3}) dt_1}{\int_0^{\infty} e^{-(\lambda_{\pi}-\lambda_{\mu})t_1} (e^{-\lambda_{\mu} t_2} - e^{-\lambda_{\mu} t_3}) dt_1}$$

$$\tau_{\pi} = \frac{\int_0^{\infty} t_1 e^{-(\lambda_{\pi}-\lambda_{\mu})t_1} dt_1}{\int_0^{\infty} e^{-(\lambda_{\pi}-\lambda_{\mu})t_1} dt_1}$$

From the above expression it is clear that we have measured the difference of the decay constants:

$$\tau_{\pi}^{-1} = \frac{1}{(\lambda_{\pi} - \lambda_{\mu})}$$

Then the true decay constant is given by

$$\lambda_{\pi} = \lambda_{\pi}^{-1} + \lambda_{\mu}$$

$$\text{or } \tau_{\pi} = \frac{1}{\lambda_{\pi}^{-1} + \lambda_{\mu}}$$

We have found the π -meson decay constant to be approximately $3.85 \times 10^7 \text{sec.}^{-1}$. The μ -meson decay constant is $4.65 \times 10^5 \text{sec.}^{-1}$. There-

fore the effect of the above correction is to reduce the measured mean lifetimes by 1 percent.

RELIABILITY OF RESULTS

There are uncertainties in all the operations involved in the tabulation of the data. For instance it is possible that the distances between the pairs of pulses have been on the average over or under estimated. The sweep calibration could not be determined exactly and there was a slight non-linearity in the sweep speed. The number of unresolved pulses involved the fraction of time the synchrotron emitted its photon beam. This duty cycle was not accurately known and probably was not constant.

In the following table are listed the various uncertainties and estimates of their contributions to the error.

TABLE I

<u>Uncertainty</u>	Estimated error applies to	
	<u>Differential data</u>	<u>Integral data</u>
Measurement of pulse separations	± 0.02	± 0.02
Sweep calibration	± 0.005	± 0.005
Non-linearity of sweep	± 0.005	± 0.005
Number of unresolved pulses		± 0.04
Statistics	± 0.043	± 0.028
Total errors	± 0.048	± 0.053

We have found from the differential data $\tau = 2.65 \times 10^{-8}$ sec. and from the integral data $\tau = 2.605 \times 10^{-8}$ sec. Then subtracting one percent for the systematic correction and applying the above errors we find the final results of this measurement of the mean lifetime of positive π -mesons

$$\tau = (2.62 \pm 0.13) \times 10^{-8} \text{sec. differential data}$$

$$\tau = (2.58 \pm 0.14) \times 10^{-8} \text{sec. integral data}$$

and correspondingly for the half life

$$T_{1/2} = (1.82 \pm 0.09) \times 10^{-8} \text{sec.}$$

$$T_{1/2} = (1.79 \pm 0.10) \times 10^{-8} \text{sec.}$$

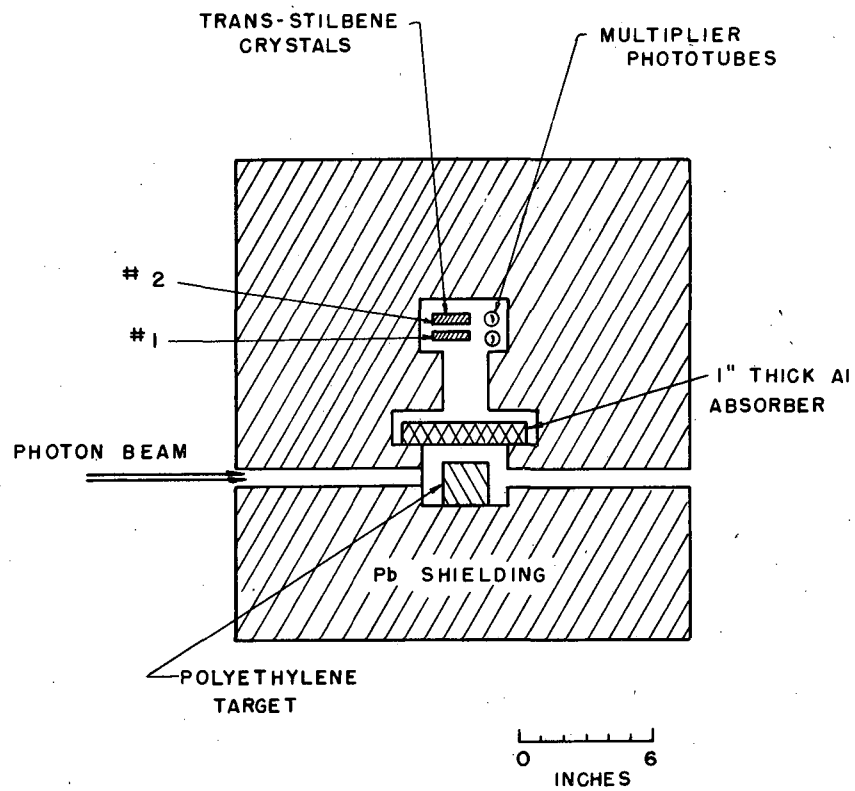
ACKNOWLEDGMENTS

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This work was performed under the auspices of the Atomic Energy Commission.

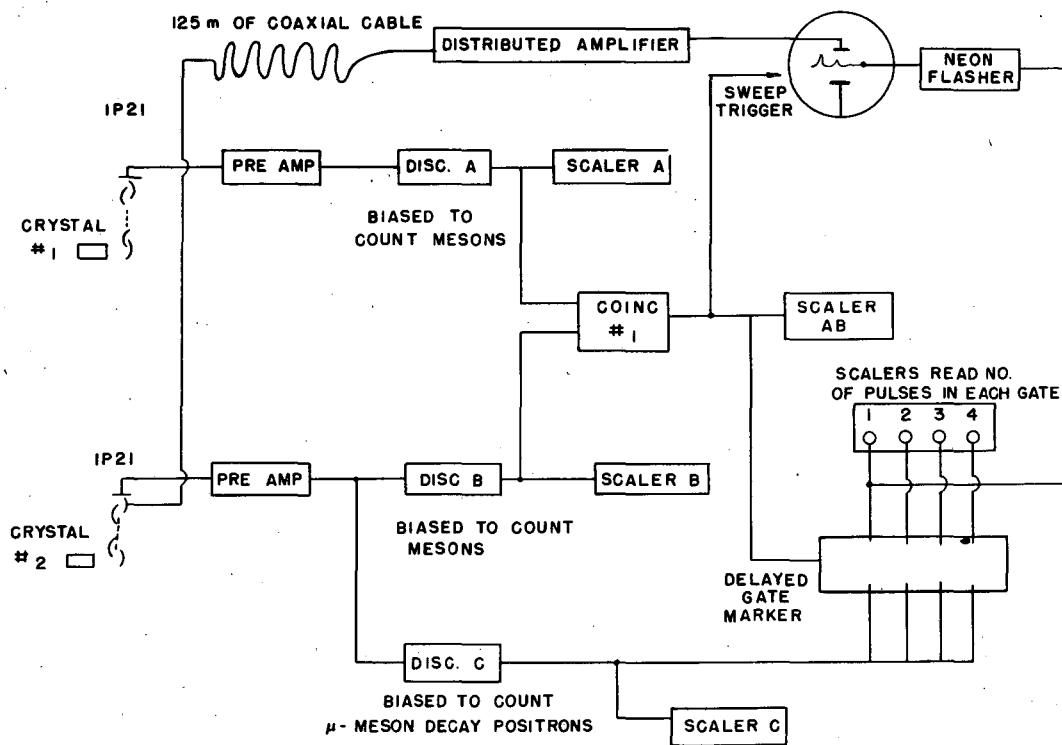
FIGURE CAPTIONS

- Figure 1. Schematic diagram of the arrangement of the detecting apparatus.
- Figure 2. Block diagram of the electronic apparatus.
- Figure 3. Schematic diagram of the distributed type vertical deflection amplifier. Resistance values are given in ohms, capacitances in micro-microfarads.
- Figure 4. Photographic reproduction of a typical oscillograph trace showing the π - μ meson decay pulses and the neon flash bulb marking. The pulse separation is about 4×10^{-8} sec.
- Figure 5. Illustration of the method of measuring the separation d between two pulses.
- Figure 6. Histogram of the number of μ -meson pulses versus the height of the pulses.
- Figure 7. Histogram of the number of measured pulse pairs versus the time of their separation.
- Figure 8. Plot of the total number of pulses occurring after a certain time versus this time.
- Figure 9. Plot of the number of pulses occurring in time intervals of $4 \times 0.362 \times 10^{-8}$ sec. versus the time.



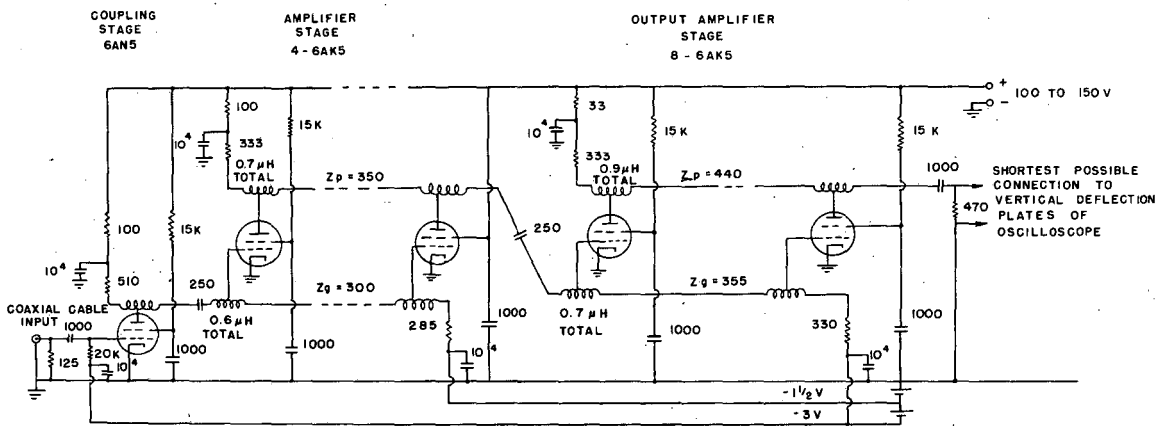
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Figure 1



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Figure 2



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Figure 3

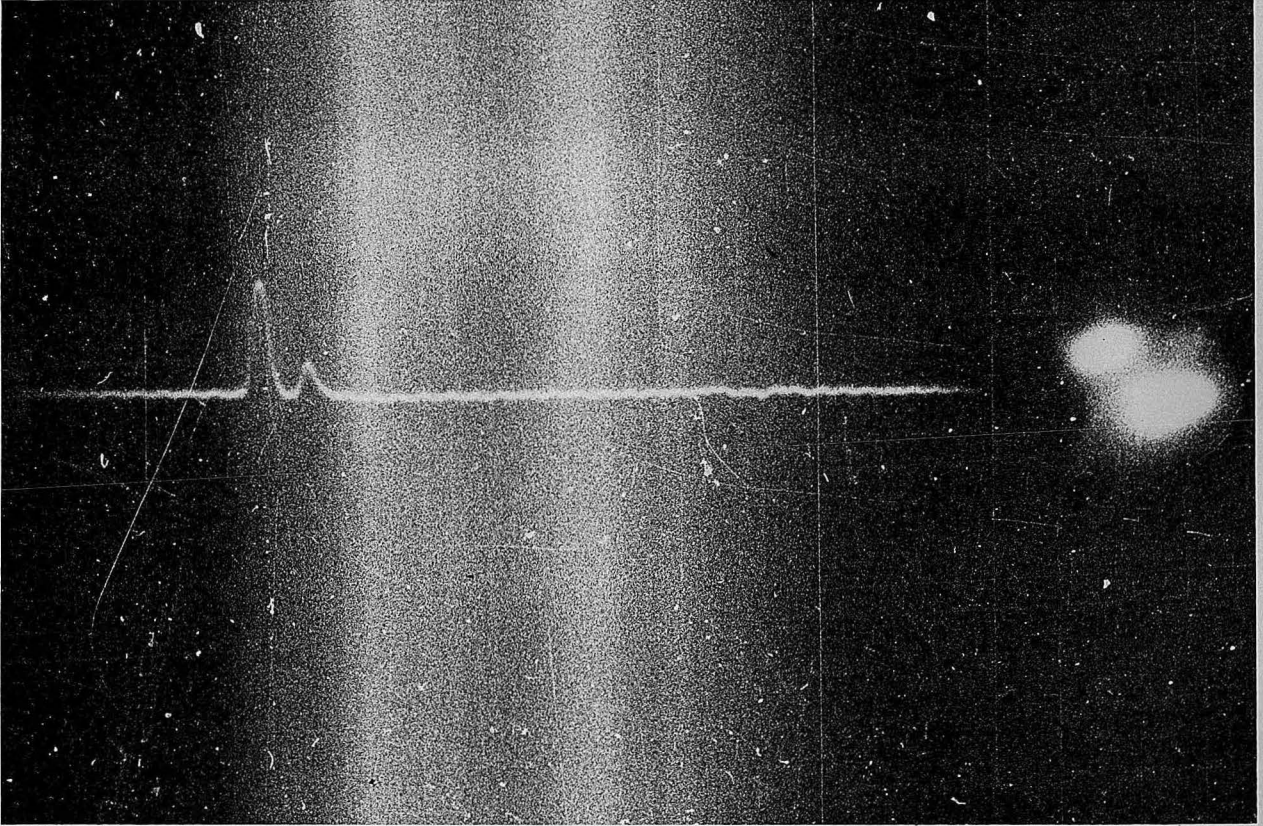
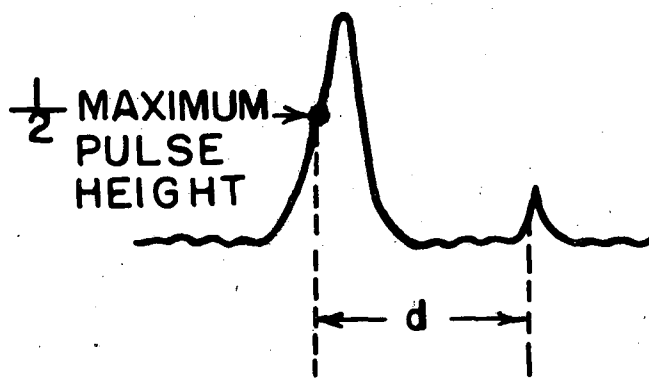
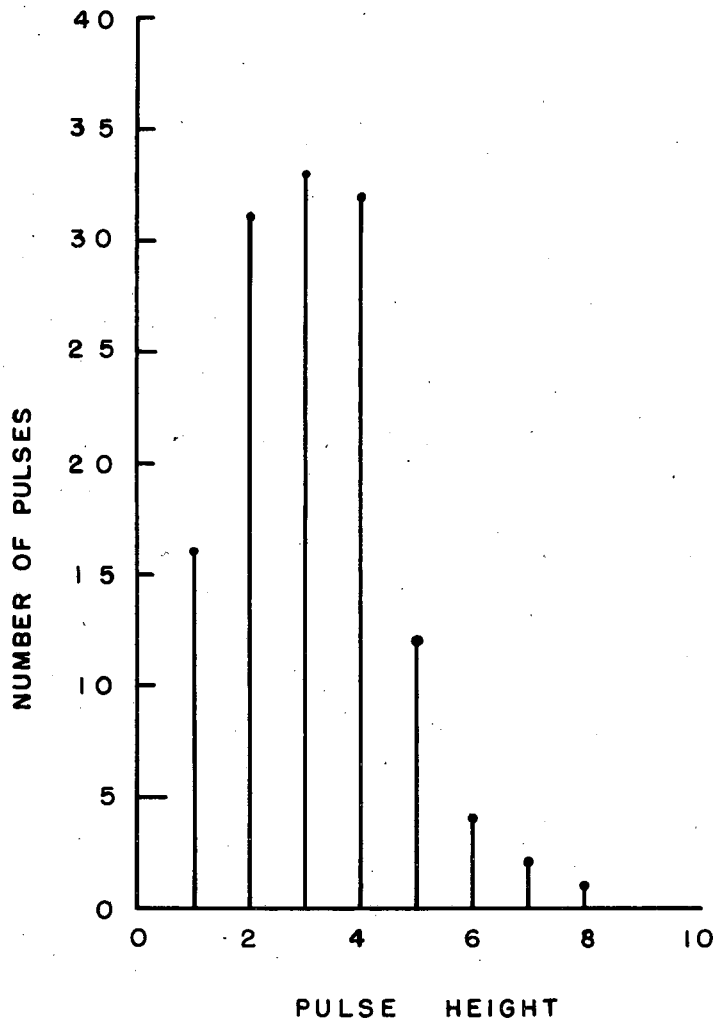


FIG. 4



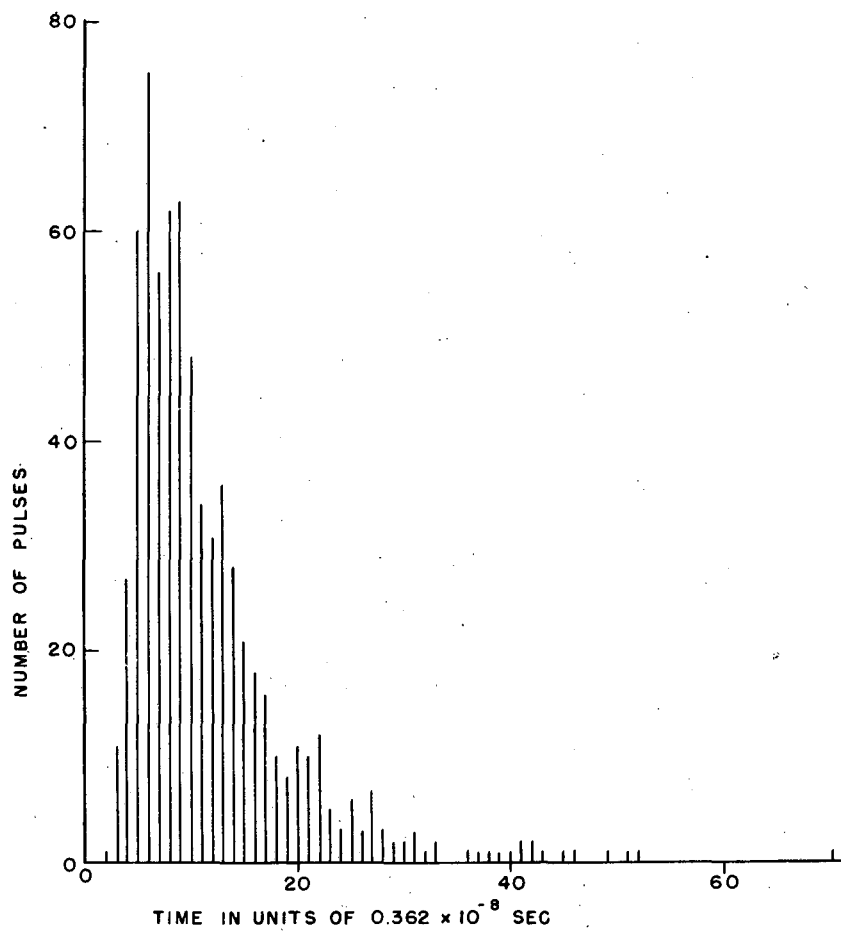
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Figure 5



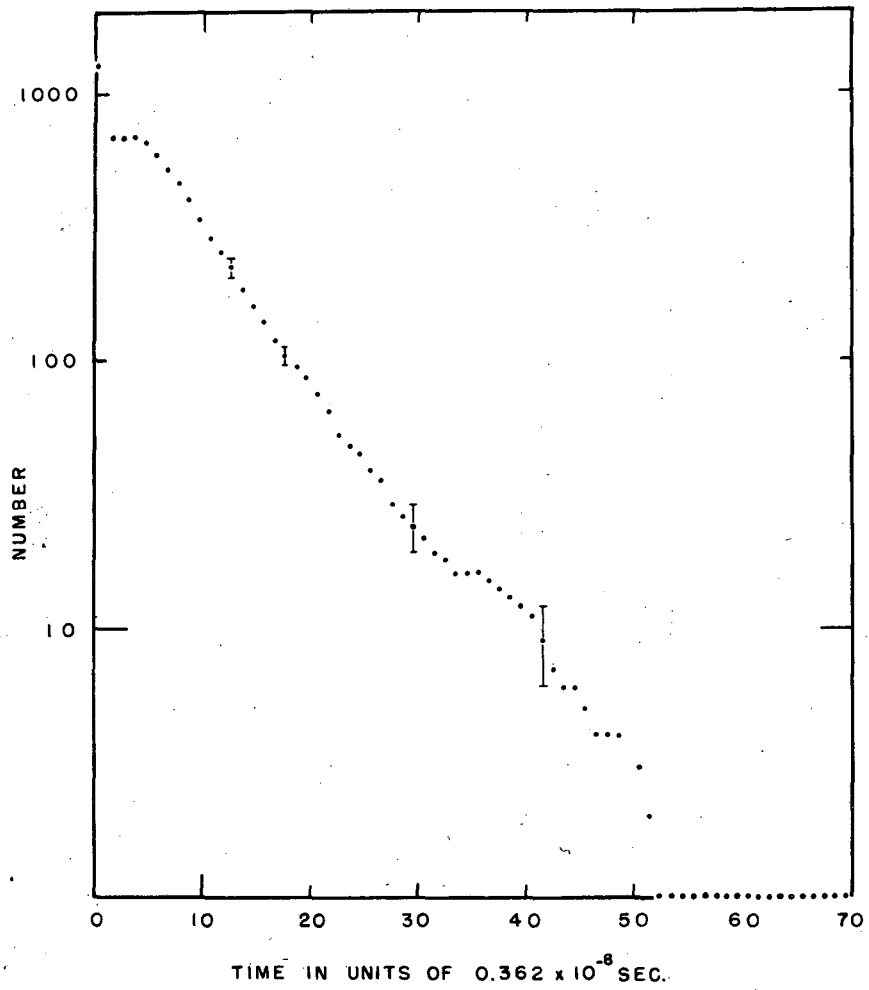
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Figure 6



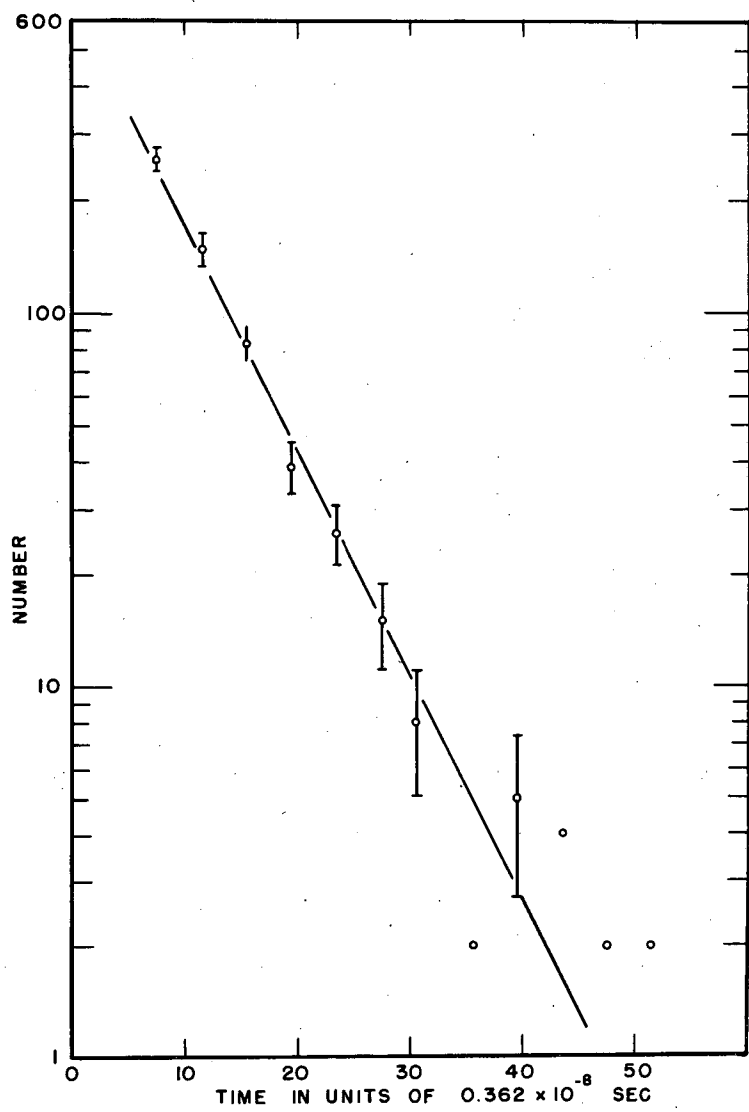
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Figure 7



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Figure 8



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Figure 9