PION BETA-DECAY

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A total of 43 pion β-decay events have been recorded with Cerenkov spectrometers. The relative probability for the decay is found to be $\lambda = (1.1 \pm 0.2) \times 10^{-8}$, which confirms the hypothesis of conservation of vector current. The values of the constants G and G_β characterizing pion and nucleon β decay are equal: $G = (1.03 \pm 0.11) G_\beta$. The energy spectrum of the positrons produced in pion β decay is in agreement with that calculated on the basis of the hypothesis of conservations of vector current.

1. INTRODUCTION

THE characteristics of pion β decay

$$\pi^+ \to \pi^0 + e^+ + \nu \qquad (1)$$

are predicted with high accuracy by the theory of weak interaction [1,2], provided the vector-current conservation hypothesis holds true [3,2]. Within the framework of this hypothesis, the probability of β decay of the pion can be determined with an error not exceeding several per cent [4,5], using the formula 1)

$$\omega(\pi^+ \to \pi^0 + e^+ + \nu) = \frac{G^2\Delta^5}{30\pi^3}\left(1 - \frac{3}{2}\frac{\Delta}{\mu} - 5\frac{m^2}{\Delta^2} + \delta\right),$$

$$\hbar = c = 1. \qquad (2)$$

Here G —weak vector interaction constant, Δ — mass difference between the charged and neutral pions [6,7], μ —mass of positive pion, m —electron mass, and δ —radiation correction.

The first investigations, made in 1961—62 [8-11], have shown that measurements of process (1) are feasible in spite of the exceedingly low relative probability

$$\lambda = \omega(\pi^+ \to \pi^0 + e^+ + \nu) / \omega(\pi^+ \to \mu^+ + \nu),$$

which, in accordance with the theory, amounts to only 1.04×10^{-8}. The probability λ obtained thereby turned out to be close to the value predicted on the basis of vector-current conservation. We present below the results of further research (see [12]) aimed at measuring the positron spectrum and at obtaining more accurate values of the probability λ.

2. EXPERIMENTAL SETUP

The pion β decay was registered with an installation [13] containing four Cerenkov total-absorption spectrometers (Fig. 1). The experiments were made with the synchrocyclotron of the Nuclear Problems Laboratory of the Joint Institute for Nuclear Research at the end of 1962. The positive pion beam extracted from the accelerator chamber was collimated with lead dia-

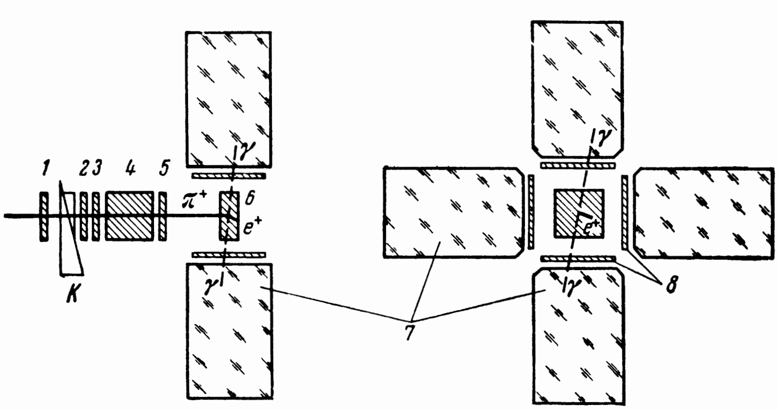

FIG. 1. Experimental setup: 1–6 – scintillation counters, 7 – Cerenkov total-absorption spectrometers, 8 – scintillation anticoincidence counters, K – slowing down filter. Photomultipliers 58AVP were used in the spectrometers, and 56AVP in the scintillation counters.

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1)Formula (2) was obtained by Gershtein[9].

phragms and magnetic lenses. The pions passed through a row of scintillation counters 1—5 and were stopped in the scintillator of the last counter, 6, intended for the registration of the decay positron. Pulse-height analysis of the output of these counters has made it possible to single out the stopped pions with assurance[14]. The γ quanta from the π^0-meson decay were registered with Cerenkov spectrometers. Scintillation counters were placed between counter 6 and the spectrometers in order to "protect" the spectrometers against charged particles (anticoincidence counters).

The scintillation counters and the Cerenkov spectrometers were placed in multi-layer magnetic screens to eliminate the influence of the stray magnetic field of the accelerator. All the counters and spectrometers were equipped with semiconductor sources of nanosecond light pulses, with the aid of which the stopping of the pion and the decay (1) could be simulated. This has made it possible to calibrate rapidly the entire apparatus during the course of the measurements.

The Cerenkov spectrometers and counter 5 were connected in a coincidence circuit[15] with delay gates of 8×10^{-8} second duration. This coincidence circuit triggered the sweep of a five-beam high-speed oscilloscope[16]. The pulse rise time on the oscilloscope screen was 4×10^{-9} sec and the vertical sensitivity was 60 mV/cm. The pulses from all the counters and spectrometers of the installation were mixed[16] and fed to the oscilloscope inputs. The pulses from counters 3, 4, 6, and 8 were width-shaped. Particular attention was paid to the shaping of the pulse from counter 6, which was fed in such a way that the bursts and the satellite-pulses were reduced to a minimum. Counter 6 was tested with two pulsed light sources, which simulated the pulse due to a stopping pion or the pulse produced some time later by the decay positron. Variation of the delay times and of the heights of these pulses has shown that the positron of decay (1) can be reliably registered if the time delay t between the instant of its occurrence and the stopping of the pion exceeds 6×10^{-9} sec. The same result was obtained in the analysis of the π^+-μ^+ decay events registered in the calibration experiments (Fig. 2a, 6).

The pulses were photographed with a Zeiss lens (East Germany) with aperture 1:0.75 and focus 100 mm. Photography was with the aid of an RFK motion picture camera and Isopanchrom-13 high-sensitivity film. The apparatus was adjusted and calibrated by recording the charge exchange of the stopped negative pions in a target located between

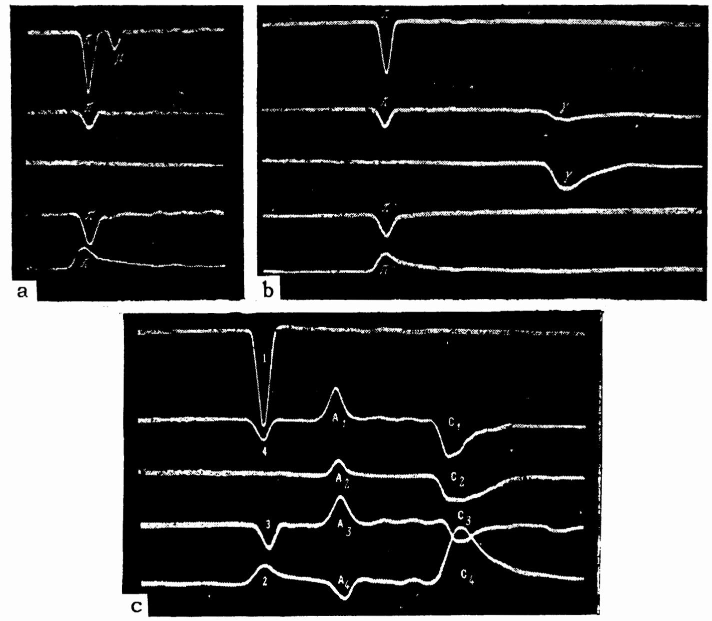

FIG. 2. a — photograph of case of $\pi^+ - \mu^+$ decays. π — pulses occurring in counters 5, 4, 3, 6 in the slowing down and stopping of a positive pion, μ — pulse in counter 6 due to the positive muon; b — photograph of charge exchange of negative pion in the scintillator of counter 6. π — the same pulses as in Fig. 2a. γ — pulses from two opposite spectrometers; c — simultaneous operation of pulse light sources in all counters and in the installation spectrometers (calibration). 2, 3, 4, 1 — pulses from counters 5, 4, 3, 6, $A_1 - A_4$ — pulses from anticoincidence counters, $C_1 - C_4$ — pulses from Cerenkov spectrometers.

the Cerenkov spectrometers. The targets used were liquid hydrogen and lithium hydride. The final calibration of the apparatus was based on an amplitude-time analysis of the photographs obtained when registering the low-intensity charge exchange process $\pi^- + p \rightarrow \pi^0 + n$[17] in the scintillator of counter 6 (Fig. 2b). This analysis has shown that the chosen method of registration ensures a resolution time of 2×10^{-10} sec for the scintillation counter and 7×10^{-10} sec for the spectrometers.

3. MEASUREMENTS

The main measurements lasted about 500 hours, with some 4×10^{10} pions passing through the installation. During the measurement, control calibration of the entire apparatus was carried out every two hours with the aid of pulsed light sources (Fig. 2c). The stability and linearity of the oscilloscope sweep was checked by photographing standard 100-Mc sinusoidal signals from a quartz-stabilized oscillator. Along with this, control experiments, in which charge exchange of the negative pions in the scintillator of counter 6 and

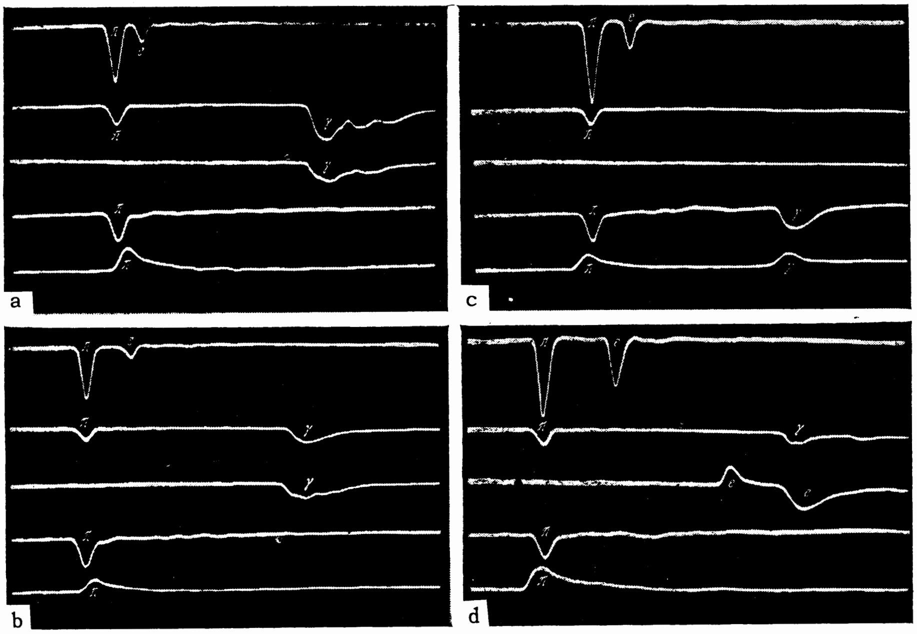

FIG. 3. a, b, c – typical photograph of pion β decay: π and γ – the same pulses as in Fig. 2b, e – pulses from decay positron (t = 17.31 and 25 nsec, respectively). d – photograph of radiative capture $\pi^+ \to \gamma + e^+ + \nu$; π and γ – the same pulses as in Fig. 2b; e – pulses from positrons in counters 6 and 8 and in the spectrometer.

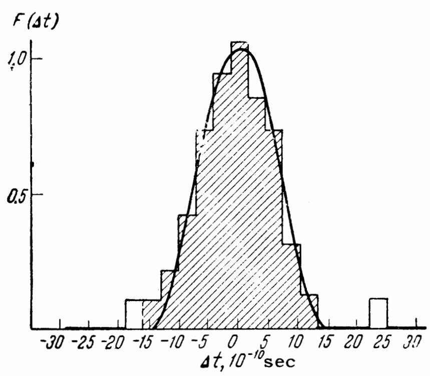

FIG. 4. Time distribution of registered events. Δt – delay of pulse from counter 6 (positron) relative to the pulses from the spectrometers. Curve – the same distribution obtained in calibration experiments when registering negative pion charge exchange.

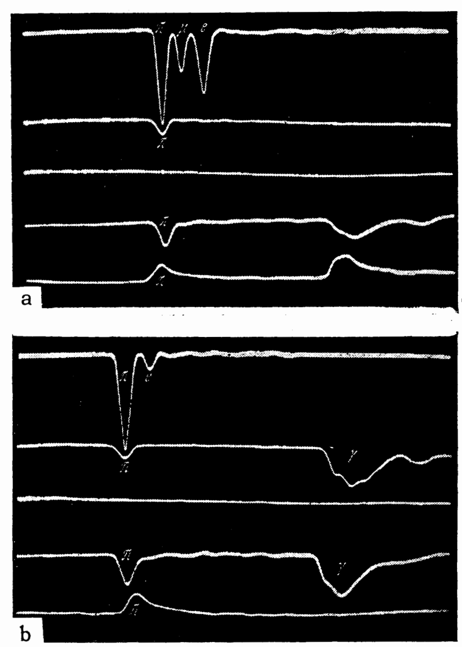

FIG. 5. Photograph of one case when a pulse from a positive muon is seen between the pulses from the pion and positron; b – the same as in Fig. 3a, but the γ quanta were registered by two neighboring spectrometers; $t = 15 \times 10^{-9}$ sec.

in the lithium-hydride target was registered, were periodically repeated.

The obtained photographs were first viewed in a diascope, to select the cases in which the photograph showed the stopping of a pion accompanied by a delayed pulse, and showed no pulses from the anticoincidence counters (Figs. 3a, b, c). Photographs on which pulses from the anticoincidence counters were registered (Fig. 3d) were processed separately—they served as a source of information on the pion radiative decay $\pi^+ \to \gamma + e^+ + \nu$.

The 330 photographs remaining after the preliminary selection were time-analyzed, and 61 events satisfying the necessary time criteria (pulses from quanta and the positron coincided within the limits of the time resolution) were classified as decays of type (1). The final selection of events was based on pulse-height analysis of the Cerenkov spectrometer output. This analysis has shown that with increasing γ-quantum registration energy threshold E_{thr} the background level decreases rapidly [12], and pion β decays can be reliably separated when $E_{thr} = 30$ MeV.

After introducing the threshold $E_{thr} = 30$ MeV, 52 events satisfied the necessary time and amplitude criteria. The random-coincidence background level was determined from the time distributions of the pulses from the Cerenkov spectrometers and counter 6. One such distribution is shown in Fig. 4. The obtained number of random $\gamma\gamma$-e^+ and γe^+-γ coincidences turned out to be equal to six. The background due to the similar μ^+-e^+ decay process (with emission of γ quantum) was determined from photographs (Fig. 5a) containing a positive-muon pulse (one event) between the pulses from the stopped pion and the positron. Finally, two other background events could be expected on the basis of two registered cases with too large a positron pulse amplitude. The total number of background events was thus 9 ± 3. The number of registered pion β-decay cases was thus N = 43.

4. MEASUREMENT RESULTS

In carrying out these experiments we registered the γ-quantum pairs emitted either in opposite directions (Fig. 3) or at an angle of 90° (Fig. 5b). The γ quanta produced in the decay (1) move apart at an angle close to 180°. Under the conditions of our experiment, this could cause the expected number of pion β-decay events $N_{\parallel}$ registered by the opposite spectrometers (with allowance for the angular resolution of the installation) to exceed by one order of magnitude the number $N_{\perp}$ registered by two neighboring spectrometers: $N_{\perp}/N_{\parallel} = 0.12$. Such an angular correlation does indeed hold for the selected events:

$$N_{\perp}/N_{\parallel} = 0.16 \pm 0.11.$$

At E_{thr} = 36 MeV we have $N_{\perp}/N_{\parallel} = 0.05 \pm 0.13$.

The time distribution of the registered cases, shown in Fig. 6, also confirms the correctness of the identification of the observed decay. As can be seen from this figure, where the distribution for the ordinary π^+-μ^+ decay is shown for comparison, the average lifetime of the observed decay coincides with the average lifetime of the positive pion. The pulse-height distribution in the Cerenkov spectrometers (γ-quantum energy spectrum) is also close to that expected for the pion β decay (Fig. 7).

The energy spectrum of the positrons produced in pion β decay is shown in Fig. 8. It coincides with the spectrum calculated on the basis of the vector-conservation hypothesis and corrected with allowance for the resolution of counter 6.

The pion β decay probability was determined from the number of registered cases of decay, N, with allowance for the experimentally obtained efficiency of the installation. To determine the efficiency, the spectrometers were exposed to γ quanta from the charge exchange of negative pions in hydrogen. The place and the angle of entry of the γ quanta into the spectrometer were varied. The resultant counting rate was compared with the counting rate of γ scintillation detectors of known

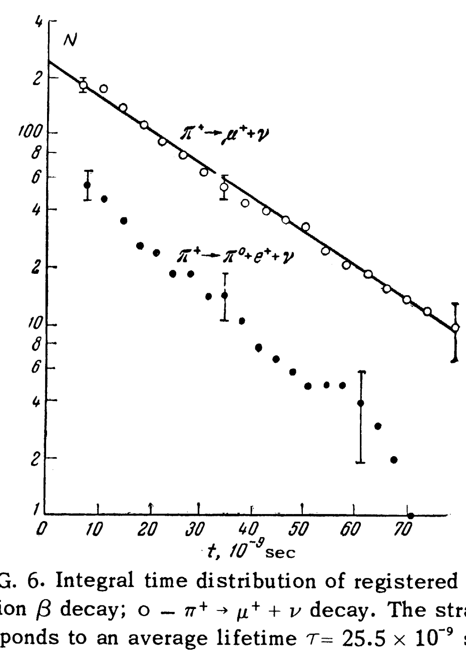

FIG. 6. Integral time distribution of registered events: • – pion β decay; o – $\pi^+ \to \mu^+ + \nu$ decay. The straight line corresponds to an average lifetime $\tau = 25.5 \times 10^{-9}$ sec.

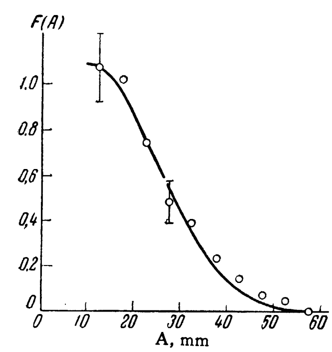

FIG. 7. Integral distribution F(A) of registered events by amplitudes A of the pulses in the Cerenkov spectrometers. Curve – the same distribution obtained in calibration experiments when registering negative pion charge exchange.

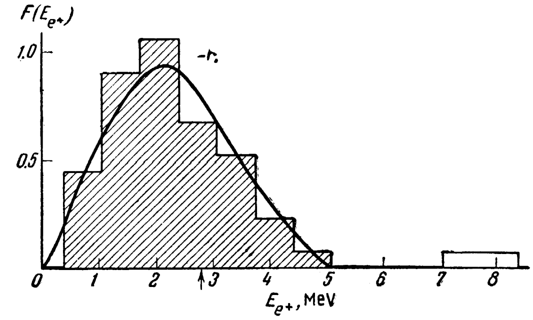

FIG. 8. Energy spectrum of positrons produced in pion β decay. The curve was calculated with allowance for the resolution of the apparatus. The arrow on the positron energy scale E_{e^+} indicates the position of the maximum in the distribution of the pulses from the positive muons in the decay $\pi^+ \to \mu^+ + \nu$.

efficiency. In determining the efficiency of the installation, account was taken of the shift and of the finite length of the gates ($10 < t < 85 \times 10^{-9}$ sec), the energy thresholds for the γ quanta ($E_{thr} = 30$ MeV) and the positron (0.6 MeV), the absorption of the γ quanta in counters 6 and 7, and the scanning efficiency. The efficiency of registration of the pion β decay was found to be 10.5 ± 1.4%.

The relative pion β decay probability was found to be

$$\lambda = (1.1 \pm 0.2) \cdot 10^{-8},$$

which agrees with the theoretically expected value. The constant G, which characterizes the pion β decay [see (2)] coincides with the vector constant G_β, which characterizes the β decay of the nuclei:

$$G = (1.03 \pm 0.11)\, G_\beta.$$

Averaging the data of the present work together with the results obtained at CERN[18], we get

$$G = (1.04 \pm 0.07)\, G_\beta.$$

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[1] Ya. B. Zel'dovich, DAN SSSR **97**, 421 (1954).

[2] R. P. Feynman and M. Gell-Mann, Phys. Rev. **109**, 193 (1958).

[3] S. S. Gershteĭn and Ya. B. Zel'dovich, JETP **29**, 698 (1955), Soviet Phys. JETP **2**, 576 (1956).

[4] G. Da Prato and G. Putzolu, Nuovo cimento **21**, 541 (1941).

[5] M. V. Terent'ev, JETP **44**, 1320 (1963), Soviet Phys. JETP **17**, 890 (1963).

[6] J. B. Czirr, Phys. Rev. **130**, 341 (1963).

[7] V. I. Petrukhin and Yu. D. Prokoshkin, JETP **45**, 1737 (1963), Soviet Phys. JETP **18**, 1190 (1964).

[8] Dunaĭtsev, Petrukhin, Prokoshkin, and Rykalin, JETP **42**, 632 and 1421 (1962), Soviet Phys. JETP **15**, 439 and 985 (1962).

[9] Dunaĭtsev, Petrukhin, Prokoshkin, and Rykalin, Phys. Lett. **1**, 138 (1962).

[10] Depommier, Heintze, Mukhin, Rubbia, Soergel, and Winter, Phys. Lett. **2**, 23 (1962).

[11] Bacastov, Elioff, Larsen, Wiegand, and Ypsilantis, Phys. Rev. Lett. **9**, 400 (1962).

[12] Dunaĭtsev, Petrukhin, Prokoshkin, and Rykalin, Intern. Conf. on Fundamental Aspects of Weak Interaction, Brookhaven, USA, (1963).

[13] Dunaĭtsev, Petrukhin, Prokoshkin, and Rykalin, Proc. 1962 Intern. Conf. on Instrum. for High-Energy Physics, Geneva, 1963, p. 252.

[14] Dunaĭtsev, Petrukhin, Prokoshkin, and Rykalin, PTÉ No. 1, 159 (1963).

[15] A. F. Dunaĭtsev and Yu. D. Prokoshkin, Preprint 1415, Dubna, 1963.

[16] Dunaĭtsev, Petrukhin, Prokoshkin, and Rykalin, PTÉ (in press); Dubna, Preprint 1588, 1964.

[17] V. I. Petrukhin and Yu. D. Prokoshkin, Nuovo cimento **28**, 99 (1963); Preprint E-1471, Dubna, (1963).

[18] Depommier, Heintze, Rubbia, and Soergel, Phys. Lett. **5**, 61 (1963).

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