cited state in Y^{89}, thought to be involved, to be 13 seconds. From these two values, together with the energy, he has designated the transition as being magnetic 2^4-pole. Goldhaber[5] has made an independent determination of approximately 16 seconds for this half-life.

The assignment by Deutsch is consistent with the shell theory of Mayer.[6] The measured spin[6,7] of Y^{89} (39 protons) in its ground state is $\frac{1}{2}$, and also is consistent with Mayer's scheme, which would put the odd proton in a $p_{\frac{1}{2}}$ state with odd parity. Similarly, the first excited state is obtained by putting this proton in a $g_{9/2}$ subshell with even parity. This fixes the gamma-transition to be magnetic 2^4-pole, in agreement with the above assignment. In the case of Zr^{89} (49 neutrons) we are concerned with a similar competition between the $g_{9/2}$ and the $p_{\frac{1}{2}}$ subshells for the odd neutron. It is probable from the results of Deutsch and Goldhaber that the 890-kev positron group proceeds from the ground state of Zr^{89} to the excited state (913±5 kev upon adding the K binding energy) of Y^{89}. Thus, if we assume a $p_{\frac{1}{2}}$ state for Zr^{89} the positron group would have to be at least third forbidden. This is not consistent with the ft value of 1.3×10^6 seconds, found in the present investigation with the aid of the curves of Feenberg and Trigg;[8] rather, the transition is either allowed or first forbidden. Accordingly, it is reasonable to assume the levels of Zr^{89} to be inverted relative to Y^{89}, with the odd neutron in a $g_{9/2}$ (even parity) ground state, thus rendering the positron spectrum allowed.

In order to find additional support for this we have investigated the 5-minute isomeric transition in Zr^{89} extensively. The sources employed were formed by irradiation of zirconium foil with 21-Mev x-rays. The half-life was found to be 4.4±0.1 minutes, with less than 1 percent of detectable background present. This is in good agreement with the value of 4.5 minutes found by Dubridge and Marshall.[9] The energy of the gamma-ray was determined with a scintillation spectrometer, by comparison with annihilation radiation at 511 kev and Ba^{137} radiation at 661 kev, to be 588±5 kev. This was confirmed by measurements of the K-conversion line in a 180° spectrometer, which gave 590±5 kev for the gamma-ray energy. The total conversion coefficient was determined, employing the scintillation spectrometer and comparing with that of the 661-kev radiation of Ba^{137}, to be 0.07±0.02. The $K/(L+M)$ ratio was separately determined in the 180° spectrometer to be 7±2. From these the K-conversion coefficient was found to be 0.06±0.02. These results, together with the lifetime, indicate the transition is magnetic 2^4-pole. This is consistent with the assignment of $p_{\frac{1}{2}}$ to the isomeric state of Zr^{89}. Accordingly, one suspects the presence of an allowed positron group going to the ground state of Y^{89}, competing with the 588-kev transition to the ground state of Zr^{89}. Absorption, magnetic spectrometer, and scintillation spectrometer results indicate a weak positron group of approximately 2.5-Mev maximum energy present to the extent of 6 percent of the conversion electrons associated with the 588-kev transition. Since the half-life of these particles was found to be 5±1 minutes, this group was attributed to the expected transition between the metastable state of Zr^{89} and the ground state of Y^{89}. A suggested partial level scheme is shown in Fig. 1. The ft value of the high energy group is 7×10^6 seconds, a value which is of the same order of magnitude as the long-lived group at 890 kev.[10]

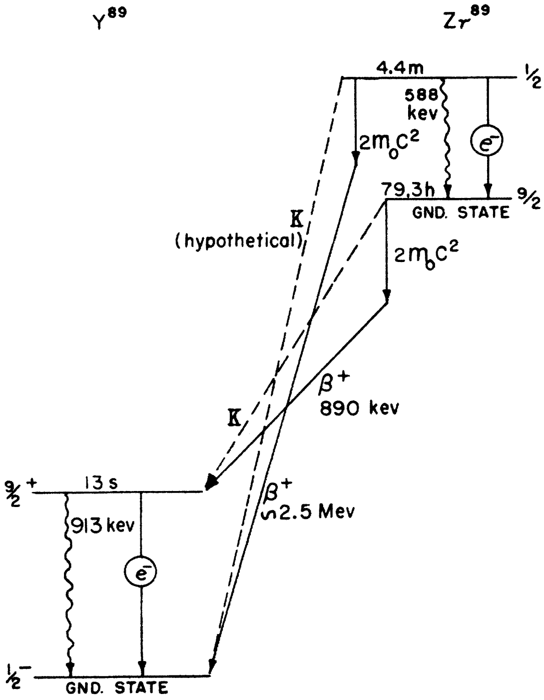

FIG. 1. Tentative partial level scheme for Zr^{89} and Y^{89}.

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[3] It has been called to the authors' attention that Hyde and O'Kelley (University of California publication UCRL-1064 (1950)) have studied chemically separated Zr^{89} and find, in addition to the conversion line (80-hr activity) mentioned above, lines at 379 kev and 1.256 Mev, of intensity, relative to that of the 896-kev line, approximately 0.2 and 0.03, respectively (as judged from their curves). The weaker of these would not have been observed in the present work; but a careful search for the 379-kev line showed that if it is present at all, it is probably less than 5 percent of the 896-kev line.

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[10] The ratio of approximately 5 between the ft values should not be regarded as significant, since sufficient uncertainty attends the higher value to permit the ratio to be anywhere in the range 4 to 7.

The Ionization Loss of μ-Mesons at Relativistic Energies in Anthracene*

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THE development of scintillation counting techniques has made it possible to measure ionization energy losses of high energy charged particles which pass through a small thickness of material. This makes it feasible to check the validity of the density effect correction to the ionization loss formula which is predicted by several authors.[1–3] μ-mesons in the cosmic radiation at sea-level provide an ideal source of relativistic particles for such an experiment because a wide range of energies is available and absorption by radiation losses and by nuclear collisions is negligibly small.

The arrangement was similar in principle to the one described in a previous paper,[4] except that two identical scintillation crystals (3 cm in diameter and 3 cm long) were used, giving two independent measurements of the energy loss of any particular μ-meson. In order to investigate the ionization loss curve at relativistic energies, lead absorbers were used to determine three energy bands for μ-mesons from (a) 190 to 460 Mev, (b) 460 to 960 Mev, and (c) higher than 960 Mev. Coincidence $ABCD$ (Fig. 1) defines a narrow beam of particles which must traverse practically equal path-lengths through both crystals. Trays E, F, and G cover the solid angle defined by $ABCD$. Counters H detect events accompanied by side showers, which are eliminated from the analysis. According to our knowledge of the energy spectrum of single electrons at sea-level, they should all be stopped in the first 12.7 cm of lead, and, therefore, do not reach tray E. Only events in which the master coincidence $ABCD$ is accompanied by pulses from counters (a) $E-(F+G)$, (b) $EF-G$, or (c) EFG are

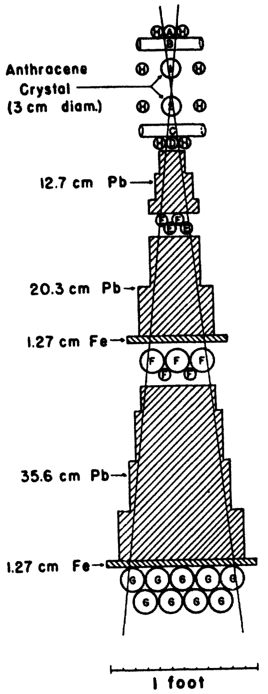

FIG. 1. Experimental arrangement.

used, as these represent the three energy-ranges for μ-mesons. The data is recorded photographically when the master coincidence *ABCD* initiates the sweep of an oscilloscope. Pulses from scintillation counters (1) and (2), as well as from Geiger-Müller counters *E*, *F*, *G*, and *H*, are each delayed with respect to the master coincidence by different fixed amounts of time; hence they appear at characteristic positions on the oscilloscope trace. This system makes it possible to obtain the data for all three energy ranges during the same run of the equipment, so that slow time variations in the apparatus cannot affect the results in comparing the data for the various energy ranges. It was estimated that the multiple scattering of mesons out of the solid angle covered by trays *F* and *G* was of no consequence for the purpose of this experiment. The pulse-height scale was calibrated in units of energy loss (Mev) with the Compton electron distribution from the 2.62-Mev gamma-line from ThC″. This should yield, in addition to an accurate relative comparison with the theory, a slightly less precise absolute comparison.

The three curves representing frequency *vs* pulse height for each scintillation counter, corresponding to energy ranges (a), (b), and (c), were found to be in agreement within experimental error with the ionization energy-loss distribution calculated by Landau[5] for charged particles traversing thin absorbers. Table I gives the most probable energy loss for each of these distributions.

The averages from the table are also shown in Fig. 2. Two additional points at 40 and 110 Mev in Fig. 2 were taken from the results of a previous experiment.[4] A correction which was made for the change in light output with the specific ionization, as found by Frey *et al.*,[6] and others, was found to be significant only for these two additional points. The solid curve is the theoretically expected curve for the most probable energy loss, when corrected for the density effect in anthracene. The density effect correction for anthracene was estimated to be similar to those for light elements as found by Wick,[2] and Halpern and Hall.[3] The uncertainty of the ordinates of the theoretical curve are of the order of 2 or 3 percent. The experimental points are seen to be in good agreement with the theoretical curve, and show, as expected, that the most probable ionization loss in anthracene indicates a relativistic increase of less than 2 percent between 300 and 3000 Mev for μ-mesons. The curve for the most probable energy loss without the density effect correction is shown for comparison. The results of this experiment appear to establish definitely the existence of the reduction in ionization loss caused by the density effect.

TABLE I. Most probable energy loss for three energy ranges.

Average energy	Most probable energy loss (Mev)		
	Counter 1	Counter 2	Average of 1 and 2
(a) 325 Mev	6.07 ±0.15	6.14 ±0.15	6.11 ±0.10
(b) 710 Mev	6.19 ±0.12	6.19 ±0.12	6.18 ±0.08
(c) 2700 Mev	6.15 ±0.07	6.15 ±0.07	6.15 ±0.05

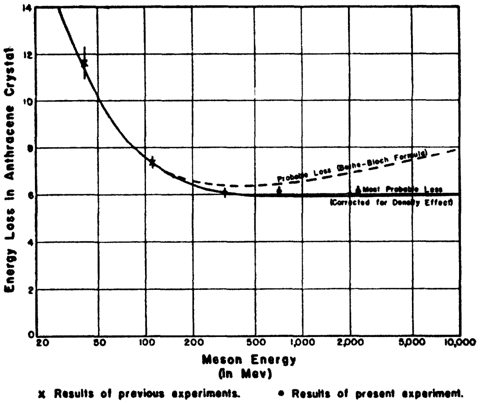

FIG. 2. Energy loss *vs* meson energy.

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Meson Scattering

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EXPERIMENTS in this laboratory[1,2] have given the cross section σ_a for nuclear events (stars, large-angle scattering, apparent absorption) produced by mesons of about 45 Mev in carbon, as well as that for diffraction scattering, σ_d. The former cross section determines the opacity $O=\sigma_a/\pi R^2$ of the nucleus and the mean free path of the meson in nuclear matter, λ, which turns out to be about $(3.7\pm0.7)\times10^{-13}$ cm corresponding to a cross section for interaction of a meson and a nucleon of 40±8 mb. The diffraction scattering has been calculated by Fernbach, Serber, and Taylor[3] and is a sensitive function of λ and of the "index of refraction" of the nucleus for mesons, defined as the ratio of the propagation vector inside the nucleus to that outside the nucleus, i.e., $(k_1+k)/k$. In Fig. 1 is plotted the diffraction scattering as a function of the opacity of the nucleus for various values[4] of k_1. In the same figure are plotted the Cornell experimental results[1] including the more recent measurements of Shapiro.[2] The rectangular box indicates the statistical standard error of the measurements.

Using the value of λ given above, one finds $k_1\lambda=0.3\pm0.3$ or $k_1=(0.8\pm0.8)\times10^{12}$ cm^{-1}. Now k_1 is related to energy of the meson