the Theoretical Group for several stimulating discussions. Sincere appreciation is expressed also to Mr. John Osher for several helpful talks on the progress of his experiment and for permission to state his results prior to publication.

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Neutron and Proton Distributions in Pb†

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In 1953, Johnson and Teller[1] proposed a model of the nucleus which predicted neutrons at larger radii than protons in nuclei with a neutron excess. Since that time some experimental data and several theoretical discussions have appeared bearing on this subject.[2] Piccioni[3] suggested that a difference between neutron and proton radii could be experimentally detected by a measurement of the difference in the absorption cross sections of a heavy nucleus for positive and negative pions of 700-Mev kinetic energy. Since $\sigma(\pi^-,p)$ is 2.6 times larger than $\sigma(\pi^+,p)$ at this energy,[4] neutrons[5] at larger radii than protons will be less transparent for π^+ than for π^-; the central region, on the other hand, is so nearly opaque that its transmission is insensitive to small changes in neutron and proton densities. Hence, the Johnson-Teller model would predict a larger absorption for positive pions than for negative. A relative measurement of this kind can be carried out with high accuracy so that even small differences can be observed.

Courant,[6] using the optical model,[7] computed the magnitude of the effect to be expected in the case of Pb. We have recomputed this effect using the recent, more accurate values of the elementary cross sections.[4] The elementary cross sections used in the calculation were averaged over a 20-Mev Fermi energy distribution. Following Courant, we used a square-well distribution, taking $r_n=r_0A^{\frac{1}{3}}$ and $r_p=r_n[Z/(A-Z)]^{\frac{1}{3}}$, which leads to equal densities of neutrons and protons within the nucleus; we also compute for $r_n=r_p=r_0A^{\frac{1}{3}}$. Results for the ratio $q=[\sigma(\pi^-)-\sigma(\pi^+)]/\sigma(\pi^+)$ are given in Table I for $r_0=1.3\times10^{-13}$ cm and 1.4×10^{-13} cm at 700-Mev and at 1100-Mev pion kinetic energies. The computed results include an electrostatic factor $[1\pm2Ze^2/RE]$.[6]

TABLE I. Calculated and experimental values for the ratio $q=[\sigma(\pi^-)-\sigma(\pi^+)]/\sigma(\pi^+)$ in Pb. The computed values are based on the optical model using square-well nucleon distributions. The values of r_0 are given in units of 10^{-13} cm.

Pion kinetic energy in Mev (lab)	$q=[\sigma(\pi^-)-\sigma(\pi^+)]/\sigma(\pi^+)$ Computed for $r_n=r_p=r_0A^{\frac{1}{3}}$		Computed for $r_n=r_0A^{\frac{1}{3}}$ $r_p=r_0[Z/(A-Z)]^{\frac{1}{3}}$		Experimental values
	$r_0=1.4$	$r_0=1.3$	$r_0=1.4$	$r_0=1.3$	
700	+0.033	+0.044	−0.027	−0.024	+0.050±0.011
1100	+0.039	+0.045	+0.030	+0.034	+0.017±0.012

The apparatus is shown in Fig. 1. Both positive and negative pions were available by simply reversing the currents in the electromagnets. The proton contamination in the pion beam was reduced to less than 1% by time-of-flight discrimination previously described.[4] The absorption was obtained by counting anticoincidences between a large final counter and the beam-defining telescope, with and without Pb absorber. The angle θ subtended by the final counter was chosen such that relatively few pions which suffer diffraction scattering or multiple Coulomb scattering are counted as absorptions. The value of q is insensitive to the fact that a small fraction of inelastic events may project a secondary within the angle θ.

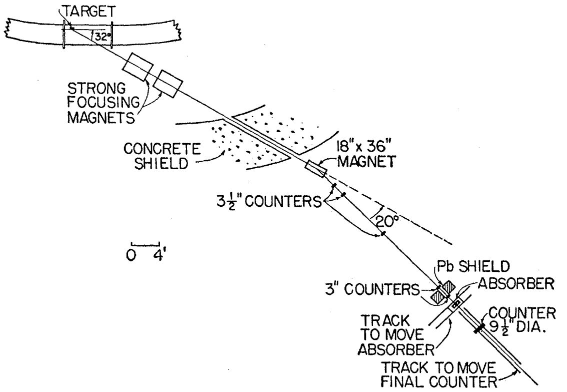

FIG. 1. Schematic arrangement of the apparatus.

The measurements have been corrected for chance coincidences in the final counter. These corrections amount to 1.3% for π^+ and 0.6% for π^-. A correction of 0.4% for π^+ was necessary because of chance coincidences in the beam-defining telescope. Muons originating from pions that decay after the momentum analysis are clearly proportional to the pion intensity and the ratio q is, to a sufficient approximation, independent of this source of muon contamination. However, muons from pions decaying before the momentum analysis are not strictly proportional to the momentum-selected pion beam intensity. This difference results from the fact that pions ranging from the selected momentum p_0 up to $1.75p_0$ can contribute muons of the correct momentum, while the π^+ and π^- production spectra are not the same. Measurements of the momentum spectra, an absorption curve in iron, and a comparison with previous UNIVAC calculations[4] lead to a correction of the π^+ cross section by $(+0.3\pm0.3)\%$. A consideration of other known asymmetric sources of muons (such as K-meson decay) leads to the conclusion that they constitute a negligible correction within our error.

Table I also shows the experimental results for the ratio q. The errors quoted are statistical standard deviations and exclude the 0.3% systematic error noted above. q was measured at 1100 Mev, where $\sigma(\pi^+,p)$ and $\sigma(\pi^-,p)$ are nearly equal, to investigate whether other sources of a difference between the π^+ and π^- absorption cross sections exist. They might arise from multibody processes, effects of the Pauli exclusion principle, or to unrecognized systematic errors. One can then compare not only the measured and calculated values of q at 700 Mev, but also compare the experimental change in q from 700 to 1100 Mev. Our value for the absorption cross section of Pb, while not of great absolute accuracy, indicates that $r_0=(1.35\pm0.05)\times10^{-13}$ cm.

If we compare our result for q at 700 Mev with the calculated values, it is evident that it agrees, within the error, with essentially equal neutron and proton radii. We can, on the other hand, compare q at 700 and 1100 Mev, taking the measured q at 1100 Mev as a normalization point. From this point of view, the data indicate that, if anything, the proton radius is somewhat larger, although this effect is only twice statistical uncertainty. An indication of the sensitivity of our measurement to a difference between r_n and r_p can be obtained from similar foregoing computations. The difference in q for unequal and equal radii is approximately linear with the difference between r_n and r_p. Our conclusion is not strongly model-dependent since we measure the relative density of neutrons and protons near the surface of the nucleus and are insensitive to detailed density distributions in the interior of the nucleus. We are now undertaking calculations using the recent Stanford results[8] for the shape of the charge distribution in the nucleus. These results will be reported in a forthcoming paper.

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