where $\dot{E}_{\mathrm{rf}}$ is the rate at which energy is gained from the rf accelerating field, which is zero in these measurements since the electrons are accelerated up to energy E and then the rf voltage is removed. $\dot{E}_\beta$ is the rate at which energy is gained by the betatron effect resulting from changing flux within the orbit. This is measured at each point of the magnetic cycle by placing a turn of wire at the orbit radius (actually above or below the donut) and measuring the peak voltage on a peak-reading vacuum tube voltmeter. The wave form is displayed on an oscilloscope, and the voltage is measured at various points in the cycle by scaling the deflection relative to the peak value. $\dot{E}_{\mathrm{rad}}$ is the rate of energy loss by radiation which we are measuring. $\dot{E}_0$ is the rate of energy loss by other means, e.g., by image currents in the conducting walls of the donut. No coherent energy loss, i.e., loss that depends on the number of electrons being accelerated, has been detected.

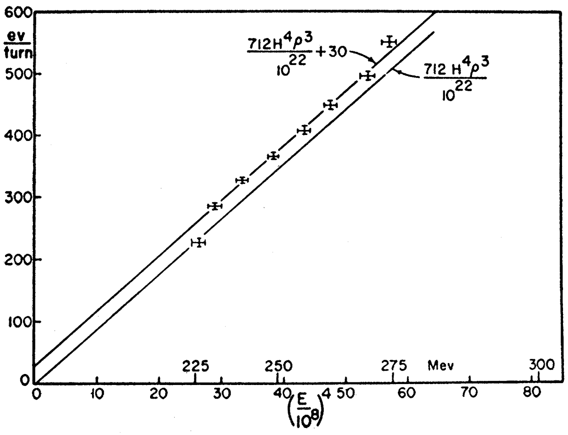

FIG. 1. Radiation loss per turn *vs* (energy)^4.

The orbit shrink rate ($\dot{\rho}$) is measured by focusing the visible radiation on to a grid placed over a photomultiplier tube. As the orbit shrinks the spot of light moves across the grid producing a modulated output from the photomultiplier. Distances inside the synchrotron donut are calibrated by intercepting the beam at different orbit radii with the synchrotron target. The radial dependence exponent (n) can be determined by comparing the orbit shrink rates at symmetrical points before and after the peak of the magnetic cycle.

The most sensitive measure of the rate of energy loss, and one which is independent of the radial magnetic field dependence, is the determination of the point on the back side of the magnetic cycle where $\dot{\rho}=0$. This point is determined by moving the rf turn-off time later and later in the cycle until the orbit is observed, as indicated by the photomultiplier signal, to move in to smaller radii and then outward again. The time at which $\dot{\rho}=0$ can be precisely determined.

H and $\dot{H}$ are determined throughout the magnetic cycle by measuring the output voltage of a coil that rotates synchronously (30 cycles/sec) with the magnetic field. By varying the phase both H and $\dot{H}$ can be measured at any point in the cycle. The coil is calibrated in a dc magnetic field with a proton magnetic resonance apparatus. H and $\dot{H}$ have also been measured by displaying on an oscilloscope the output of an annular loop of wire placed in the magnet gap.

The results for electron energies (obtained by varying the magnet current) from 225 Mev to 275 Mev are shown in Fig. 1. The engineering formula for classical energy loss, ev/turn $=(712H^4\rho^3)/10^{22}$, is also plotted. More refined measurements will be required to determine whether or not the fixed loss per turn of 30 ev indicated in Fig. 1 is real or only represents a systematic error. The $\dot{\rho}$ measurements up to 318 Mev give results close to the classical result also, but with somewhat larger uncertainties. In any case there can be little doubt of the soundness of the classical calculation for radiated power.

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* Supported in part by the ONR.

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Angular Distribution of 53-Mev Positive Pions Scattered by Protons*

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SCATTERING of positive pions with an energy of 53±10 Mev has been observed in the gas of a diffusion cloud chamber filled with 21 atmospheres of hydrogen and methanol vapor, as described previously.[1] The pions were produced by the Columbia University Nevis cyclotron.[2] 8400 photographs were obtained. Pions decaying to muons in the gas in the chamber were counted if the projected angle between pion and muon tracks amounted to more than 4°. From the 967 decay events observed, one calculates that a total pion path length of 1820 g/cm^2 of hydrogen has been scanned. In the calculation a correction of 24 percent has been applied to compensate for the $\pi-\mu$ events with angles $<4°$, many of which may be missed. Furthermore, a pion lifetime of 2.6×10^{-8} sec has been used besides the known average pion energy and gas density. The theoretical angular distribution of $\pi-\mu$ events cuts off abruptly at an angle of 17.5° if the energy of the pions is exactly 53 Mev. The measured distribution slopes off gradually up to angles $>30°$, and one must infer an average uncertainty of the pion energy of ±10 Mev. This uncertainty is partially due to a distribution in energy of the incident pions and partially due to straggling in the wall of the diffusion chamber (5 g/cm^2 of stainless steel).

Twenty-one scattering events were observed, leading to a total cross section of 20±4 millibarns. This value, which is equal to $\frac{1}{3}$ of the geometrical cross section defined by $3.14(\hbar/m_\pi c)$,[2] agrees with the Chicago result[3] of 20±10 mb measured at 56 Mev and probably also agrees with the Columbia result[4] of 27.8±2.5 mb measured at an average energy of 58 Mev. According to the Chicago measurements,[3] the cross section increases rapidly with energy at such energies; therefore, differences or fluctuations in the energy of the incident pions can easily lead to relatively large differences or uncertainties in the experimentally determined cross sections.

The value of 20 mb for the π^+-p cross section should be compared with the very small value of approximately 3 mb found for the π^--p cross section for ordinary scattering.[1] As discussed in reference 3, this big difference is very probably due to the contribution of charge exchange scattering to the total π^--p cross section, not easily observable by the present method, and due to the particularly rapid increase of the π^+-p resonance scattering cross section with energy.

All of the observed events are consistent with the kinematic conditions for elastic π^+-p scattering (coplanarity, consistent angles, and consistent ranges and ionization density wherever possible to determine). The measured angles (θ) between ingoing and outgoing pion tracks have been transformed to the center-of-mass system (θ_0), and the differential cross section $d\sigma/d\omega$(mb/sterad) has been plotted against θ_0 (Fig. 1). Events with $\theta_0<20°$ could not be counted because of the shortness of the proton recoil track and the resulting confusion with $\pi-\mu$ decays. The isotropic, $\cos^2\theta_0$, and $(1+3\cos^2\theta_0)$ distributions have also been indicated in Fig. 1. Comparison, including a χ^2-test, shows that the isotropic distribution is quite inconsistent with the experimental data, while either one of the other distributions may be consistent.

The present result does not agree with the theory of Ashkin *et al.*,[5] employing the "weak coupling" approximation and pre-

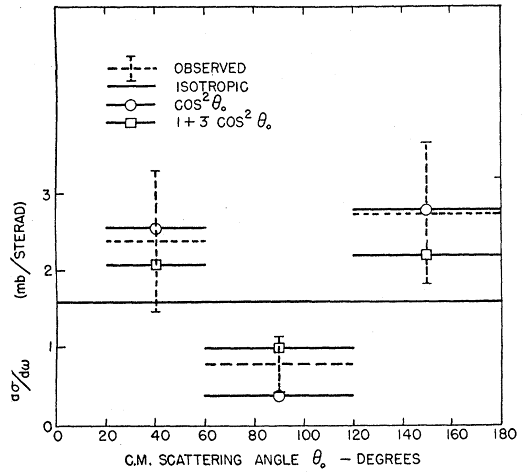

FIG. 1. Experimental π^+-p differential scattering distribution in the center-of-mass system. Distributions of the forms $\cos^2\theta_0$ and $1+3\cos^2\theta_0$ are also indicated besides the isotropic distribution.

dicting a practically isotropic distribution for the low meson energies considered here. The results obtained by the Chicago group[3] have already indicated the validity of a "strong coupling" theory,[6] the characteristic features of which have been pointed out by Brueckner.[7] For pseudoscalar mesons (spin 0) and pseudovector interaction, p-wave scattering must predominate, and the total angular momentum can assume the values $1\pm\frac{1}{2}$. As further pointed out by the Chicago group, the scattering in the angular momentum state $\frac{1}{2}$ should lead to an isotropic distribution, while in the state $\frac{3}{2}$ a distribution of the form $1+3\cos^2\theta_0$ is expected. Furthermore, interference effects can lead to a $\cos\theta_0$ term. Thus, the present result can be tentatively identified as being due to scattering in the angular momentum state $\frac{3}{2}$ alone.

We are indebted to the Nevis cyclotron staff for the opportunity to operate there and for the generous cooperation of members of the staff and operating crew.

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* Work done at Brookhaven National Laboratory under the auspices of the AEC.

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Photodisintegration of the Deuteron at High Energies

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RECENT experiments[1,2] on the photodisintegration of the deuteron at high energies give evidence of cross sections exceeding what might be expected on the basis of earlier calculations.[3,4] The discrepancy seems to be appreciable for energies above about 80 Mev.

In previous treatments, which admittedly are not applicable at very high energies, the contributions from charged mesons are only taken into account as giving rise to the exchange interactions and the anomalous magnetic moments for the nucleons.[5] It is, however, conceivable that at sufficiently high energies the meson exchange currents in the deuteron will play the dominant rôle in the photoeffect.

Using ordinary perturbation theory we have, therefore, calculated the contribution to the cross section from processes in which a π-meson is emitted by one of the nucleons, absorbs the photon, and is then absorbed by the other nucleon. The nucleons are treated nonrelativistically and plane waves are used in the intermediate and final states. The ground state of the deuteron is described by a wave function of the Hulthén form. Pseudoscalar meson theory is applied.

It turns out that calculations with pseudovector coupling give total cross sections in reasonable agreement with experiment, while pseudoscalar coupling affords too low values. The result may, therefore, serve as a further argument for the pseudovector coupling form of the pseudoscalar theory.

The predominance at high energies of the process considered by us over the direct absorption of the photon by the nucleons may be understood in the following way. Firstly, the absorption of a photon by a meson instead of by a nucleon is favored by the smaller mass of the meson. Secondly, the cross section for the direct absorption contains a factor giving the probability of finding a nucleon in the deuteron with momentum $\mathbf{p}-\mathbf{k}$, where $\mathbf{p}$ is the final momentum of the absorbing nucleon and $\mathbf{k}$ is the momentum of the photon. For increasing energies the cross section is, therefore, rapidly decreasing. On the other hand, in the indirect process the emission of a meson of momentum $\mathbf{q}$ gives rise to a matrix element, the squared amplitude of which measures the probability of finding a nucleon with momentum $\mathbf{p}+\mathbf{q}$ in the deuteron. Since $\mathbf{q}$ may be chosen so as to give a small value of $\mathbf{p}+\mathbf{q}$, large contributions to the cross section will be obtained from meson momenta roughly satisfying $\mathbf{q}\approx-\mathbf{p}$.

A further account will appear in *Arkiv für Fysik.*

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Internal Conversion in Cu^{64} and Fe^{59}†

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MEASUREMENTS of the K-conversion coefficients of the 1.34-Mev γ-ray of Cu^{64} and the 1.11-Mev and 1.30-Mev γ-rays of Fe^{59} have been taken, using the β-ray spectroscope ($\rho=50$ cm) recently constructed at Carnegie Institute of Technology. In all cases the coefficient was obtained by measuring the ratio of the number of conversion electrons to the number of β-rays in a component of the continuous spectrum. This value was divided by the number of γ-rays per β-ray as found from a decay scheme.

TABLE I. Observed K-conversion coefficients, α_K.

Original nucleus	Nucleus emitting γ-ray	Energy of γ-ray (Mev)	α_K	Number of sources used
Cu^{64}	Ni^{64}	1.34	$(1.0\text{–}1.6)\times10^{-4}$	2
Fe^{59}	Co^{59}	1.11	$(1.45\pm0.05)\times10^{-4}$	1
Fe^{59}	Co^{59}	1.30	$(0.84\pm0.05)\times10^{-4}$	1

To obtain the continuous spectrum below the cut-off point of the counter windows, the Kurie plots for these spectra were extrapolated. It is felt that, for this reason, the α_K value for the Cu^{64} γ-ray was high. The Cu^{64} sources used were rather thick ($\sim$10 mg/cm^2) and this thickness increases the relative number of slow electrons. Using the data of Tyler,[1] a rough estimate was made of the effect of source thickness, and the coefficient given includes this correction.