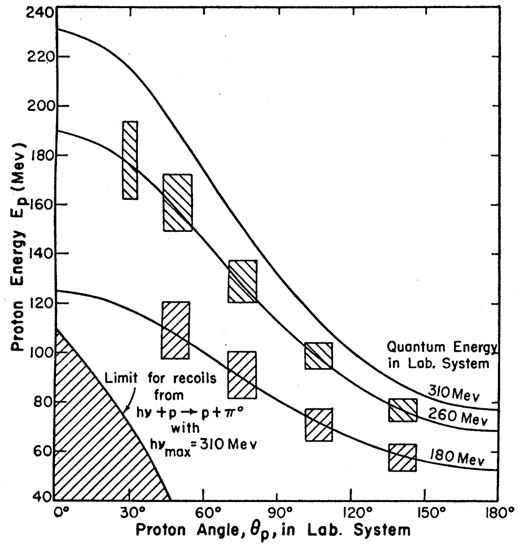

FIG. 1. Kinematics of the photodisintegration.

in the beam calibration obtained this way is ±15 percent, which we believe to be the main uncertainty in the absolute scale of cross sections of this experiment.

Figure 2 shows the cross sections for photodisintegration measured at the two energies as a function of proton angle in the c.m. system. For comparison, we have plotted the points obtained by Benedict and Woodward[1] at 160 Mev on the same figure. Except for a point in the back hemisphere, agreement is seen to be good.

The statistical errors make it impossible to determine the angular distributions very well. The points are consistent with an isotropic distribution at both energies, and it would be difficult to accommodate anisotropic terms to more than about 50 percent. For lack of better information, we have computed the total cross sections under the assumption that the angular distributions are isotropic. This contrasts with the treatment of Benedict and Woodward, who fitted a distribution of the form $\sin^2\theta(a+b\cos\theta)+c$ to their experimental points. At 160 Mev, they found $b\sim c\sim 0.4a$, subject to some uncertainty because only three points in the angular distribution were measured.

Figure 3 gives the total cross sections as a function of quantum energy in the c.m. system. We have shown the data of Benedict and Woodward as well as our own, together with a curve taken from the paper by Schiff.[4] The experimental errors shown are

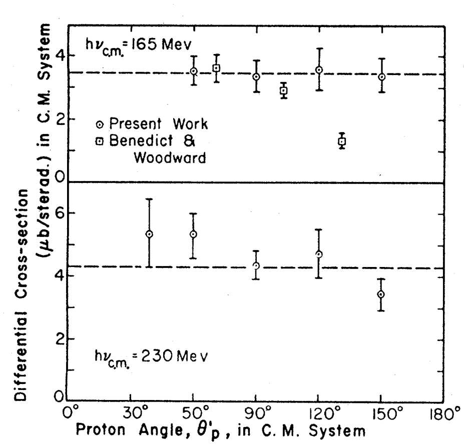

FIG. 2. Differential cross sections in the c.m. system.

statistical; in addition, there is an over-all uncertainty of about ±20 percent in the absolute scale for our data and ±30 percent for that of Benedict and Woodward.[8] Most of the disagreement between the two points at 160 Mev can be traced to the difficulty of angular integration pointed out above and indicates the extent to which the total cross section is uncertain at present.

Our values are considerably lower than those reported by Gilbert and Rose,[2] who, however, allow an error of a factor of two in their absolute cross sections. The recent data of Kikuchi,[3] obtained by multiplying the 90° differential cross section by 4π, agrees with our results, although the stated error is a factor of three. Kikuchi also reports a forward asymmetry of the photoprotons in the c.m. system, for which we have here not found any strong indication.

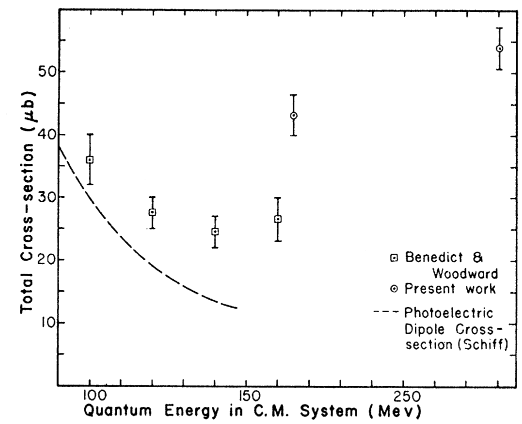

FIG. 3. Total cross sections in the c.m. system.

In summary, it appears at present that the photodisintegration cross section begins to deviate from the phenomenological electric dipole cross section in the region of the meson threshold, and thereafter rises slowly with increasing quantum energy. The total cross section at 230 Mev is of the order of 50 μb. The angular distribution of the photoprotons shows no very marked anisotropy.

* Work done under contract with the ONR.
[1] T. S. Benedict and W. M. Woodward, Phys. Rev. **85**, 924 (1952).
[2] W. S. Gilbert and J. W. Rose, Phys. Rev. **85**, 766 (1952).
[3] S. Kikuchi, Phys. Rev. **85**, 1062 (1952).
[4] L. I. Schiff, Phys. Rev. **78**, 733 (1950).
[5] J. F. Marshall and E. Guth, Phys. Rev. **78**, 738 (1950).
[6] This calibration was carried out by Professor J. W. DeWire.
[7] Dr. A. M. Perry undertook most of the shower curve measurements.
[8] Since the same beam calibration was used for the two experiments, however, these errors are not entirely independent.

Radiation Loss by Electrons in Large Orbits*

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DOUBT has recently been raised[1] concerning the validity of the classical calculations[2] of radiation loss by electrons moving in large orbits in a uniform magnetic field. Parzen's[1] quantum mechanical calculations indicated a much smaller total energy loss than is given by classical theory.

The radiation loss can be measured by observing how the orbit radius in a synchrotron changes with time when the radio frequency accelerating voltage is removed. We have $E\doteq 300H\rho$ and $H=H_0(\rho_0/\rho)^n$, where E is measured in electron volts, H in gauss, and ρ in cm. When both the orbit radius and time are allowed to vary we have

$$\dot{E}/E=(1-n)\dot{\rho}/\rho+\dot{H}/H.$$

Here $\dot{E}$ is the total rate of change of the electron's energy:

$$\dot{E}=\dot{E}_{rf}+\dot{E}_{\beta}+\dot{E}_{rad}+\dot{E}_0,$$

where $\dot{E}_{rf}$ 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. $\dot{E}_{rad}$ 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.

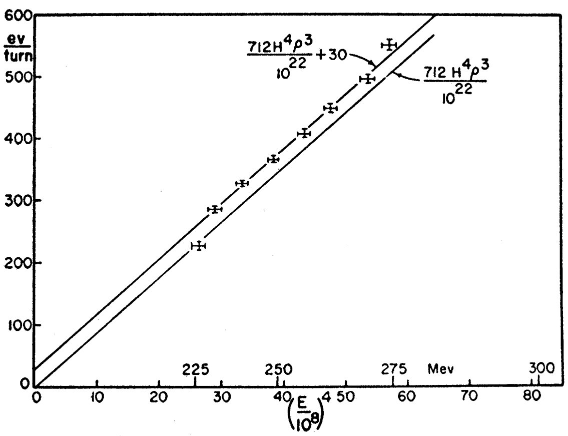

FIG. 1. Radiation loss per turn *vs* (energy)^4.

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.

* Supported in part by the ONR.
[1] G. Parzen, Phys. Rev, **84**, 235 (1951). See also the following Letters which appeared after this manuscript was completed: Judd, Lepore, Ruderman, and Wolff, Phys Rev. **86**, 123 (1952); H. Olsen and H. Wergeland, Phys. Rev. **86**, 123 (1952).
[2] J. Schwinger, Phys. Rev. **75**, 1912 (1949).

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-