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EXPERIMENTS WITH HIGH ENERGY POLARIZED PROTONS

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There have been recent reports[1,2] on high energy polarized proton beams and their scattering properties. We also have been scattering protons in the Berkeley cyclotron and investigating their polarization by double scattering experiments and we wish to give at this time a progress report because the data so far collected appear of interest.

The beam is polarized by scattering on target A of beryllium or carbon (Fig. 1) and is deflected by a steering magnet into the shielded experimental area (cave).

The angle of scattering Ψ in a horizontal plane and at target A varies between 17° and 20° in different experiments. The energy E_0 of the primary beam is 340 Mev. The scattered beam follows an orbit as drawn in Fig. 1 and its energy is approximately $E = E_0 \cos^2 \Psi$ as if it underwent an elastic scattering on a free nucleon. E is measured by a range determination.

The following experiments show that the beam between targets A and B is polarized: A second scatterer B, in the cave, scatters the beam by an angle Θ. To completely define the direction of the scattered beam we need also an angle Φ between the plane of the incident and scattered beam and the horizontal plane in which Ψ has been measured. For a given Θ the scattered intensity I is a function of Φ and we call

$$e(\Theta) = \left[I\,(\Phi = 0^{\circ}) - I\,(\Phi = 180^{\circ}) \right] / \left[I\,(\Phi = 0^{\circ}) + I\,(\Phi = 180^{\circ}) \right].$$

Using targets A and B of carbon, measured values of I at $\Theta = 15^\circ$ are as follows: $I(\Phi = 0^\circ) = 134.1 \pm 4.0$; $I(\Phi = 90^\circ) = 101.8 \pm 3.7$; $I(\Phi = 180^\circ) = 59.3 \pm 4.3$; $I(\Phi = 270^\circ) = 104.7 \pm 3.3$ from which $e = 0.39 \pm 0.04$ and $\left[I(\Phi = 90^\circ) - I(\Phi = 270^\circ)\right] / \left[I(\Phi = 90^\circ) + I(\Phi = 270^\circ)\right] = 0.01 \pm 0.02$, which is a satisfactory check indicating that the polarization is a real effect.

When liquid hydrogen was used as scatterer B we found that $e(\vartheta)$, where ϑ is the scattering angle in the c.m. system, is given by the curve of Fig. 2. It will be noticed that $e(90^\circ_{c.m.})$ is consistent with zero as it should be for reasons of symmetry. These checks and an accurate study of the alignment, geometry, and counter properties, which we do not now report, have convinced us that the polarization effect is real. Furthermore we have checked that the external beam extracted in the ordinary way shows no asymmetry with either hydrogen or carbon as target B. (This confirms the fact that our p-p scattering experiments[3] were not influenced by polarization effects.)

The absolute intensity of the polarized beam entering the cave was approximately 2×10^5 protons per second over an area of 5 cm^2.

In order to use the polarized beam for quantitative measurements we would like to know its degree of polarization $P = (F_+ - F_-)/(F_+ + F_-)$ where $F_\pm$ is the intensity of the protons with spin up or down respectively. If the scatterings in targets A and B were elastic, and the targets were of the same material, and if Θ' equals Ψ, then P equals $\sqrt{e}$ at least approximately. (We neglect the degradation of energy.) At present we have no completely satisfactory way of knowing the degree of polarization of the beam.

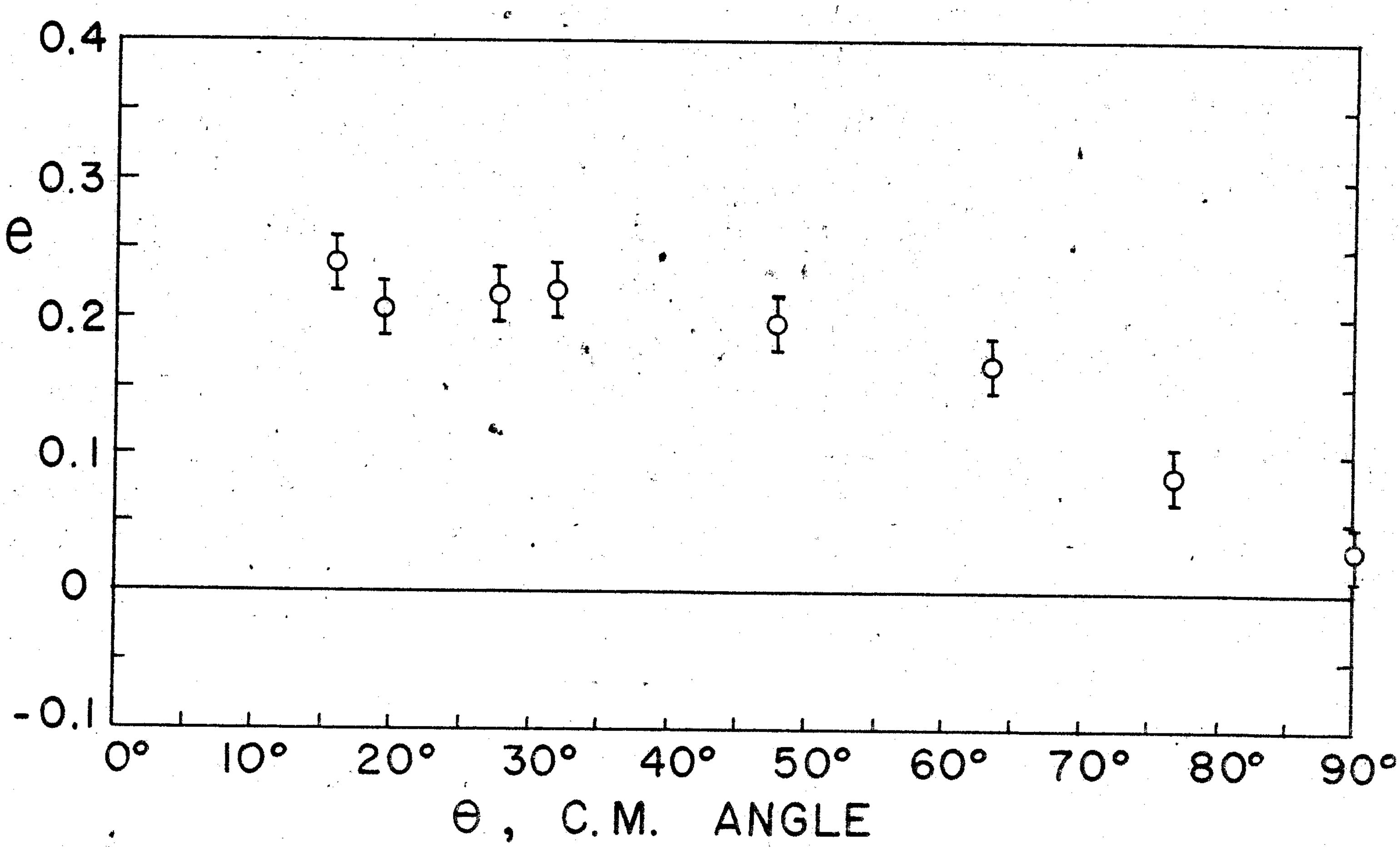

FIGURE 2

A curve with targets A and B of carbon is given in Fig. 3. This curve is obtained with an absorber in the telescope which would cut off protons with an energy smaller than 3/4 of the energy $E \cos^2 \Theta$ which would obtain in an elastic nucleon nucleon scattering. It shows that at 30° the polarization is sufficiently small to have escaped Marshall, Nedzel, and Marshall.

Since in the case of carbon a large part of the scattering might be inelastic, especially at large Θ, it is important to investigate e not only as a function of Θ but also of the energy of the protons detected. We have started this investigation by taking measurements with various energy cutoff values by inserting various absorber thicknesses in our counter telescope at $\Theta = 15°$ and 9°. In each case the lowest energy group of scattered protons (0 to 210 Mev) shows no observable asymmetry. For $\Theta = 15°$ the intermediate energy group (210 to 280 Mev, quasielastic scattering) gives large asymmetry with $e = 0.37 \pm 0.04$, and the elastically scattered protons (290 Mev) indicate $e = 0.45 \pm 0.04$. For $\Theta = 9°$, the elastically scattered protons show $e = 0.43 \pm 0.02$.

If the beam polarization P were known, we could determine the polarization in scattering by hydrogen P_H from the relation $e_H = P P_H$. If we tentatively assume that $e_C = P^2$ (even though the carbon scattering is not elastic) then we obtain from the data for $\Psi = \Theta = 20°$ the result $P = 0.5$, and $P_H = 2 e_H$. This allows a provisional interpretation of the data of Fig. 2. Quite aside from the absolute value of P_H, its angular distribution is given in Fig. 2 and this indicates a more complex dependence than the sin (2ϑ) dependence obtained by considering only s and p-waves.

This work was done under the auspices of the Atomic Energy Commission.

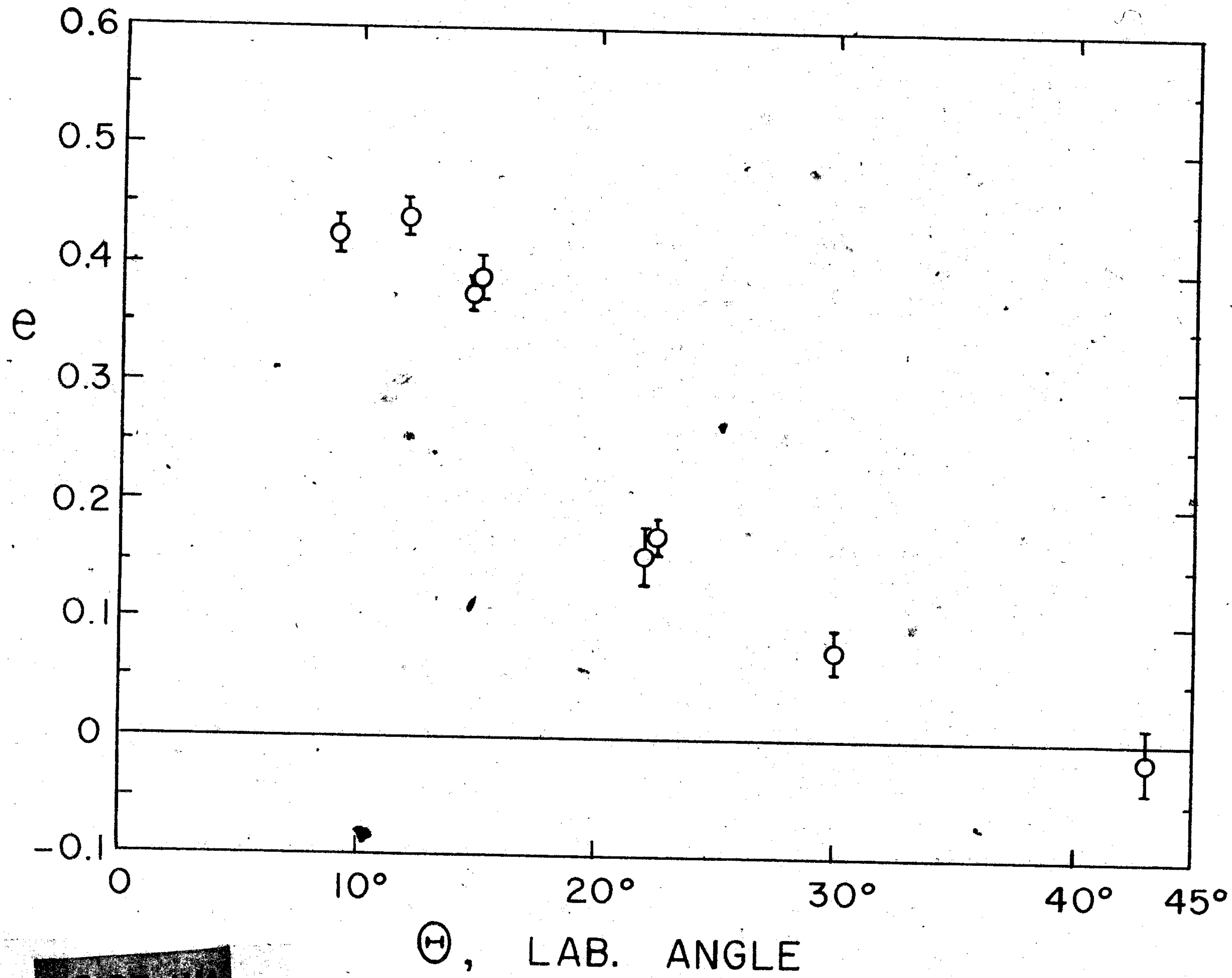

FIGURE 3

(1) Oxley, Cartwright, Rouvina, Baskir, Klein, Roy and Skillman Phys. Rev. 91, 419 (1953)

(2) Marshall, Nedzel and Marshall; Bull. Am. Phys. Soc. 28, No. 6, 23 (1953)

(3) Chamberlain, Segre, and Wiegand; Phys. Rev. 83, 923 (1951)

Fig. 1. Plan view of the experimental arrangement showing the angles Ψ and Θ at the first and second targets. The angle Φ, measuring rotation of the apparatus in the cave around the beam, is equal to zero for the configuration shown.

Fig. 2. The asymmetry parameter e plotted as a function of the center-of-mass scattering angle ϑ for proton-proton scattering at target B. The errors shown include only counting statistics.

Fig. 3. The asymmetry parameter e plotted as a function of the laboratory angle Θ for scattering from a carbon target at position B. Different absorbers were used in the counter telescope at different angles as outlined in the text. The errors shown indicate counting statistical errors.

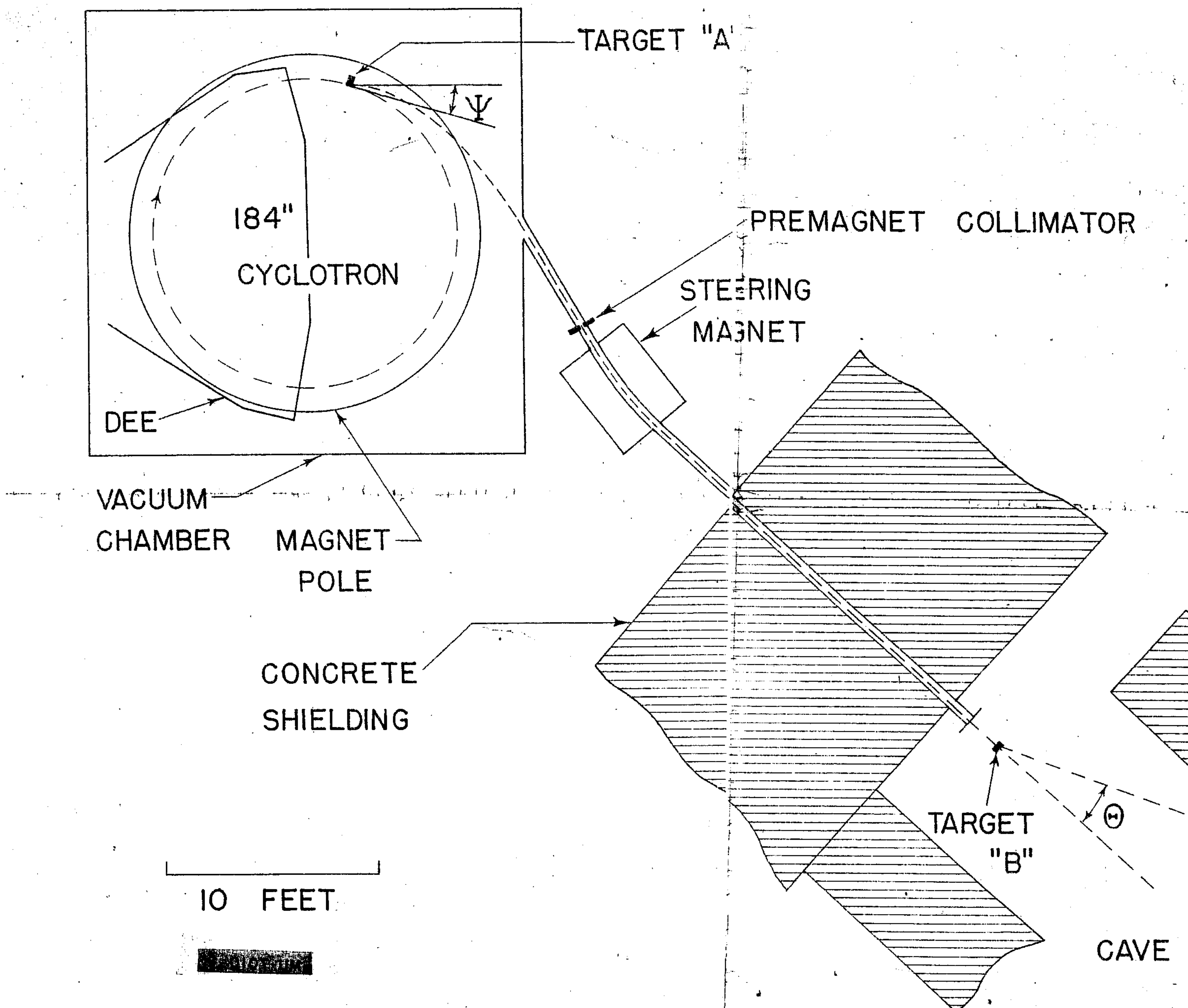
TARGET "A"
Ψ
184"
CYCLOTRON
PREMAGNET COLLIMATOR
STEERING
MAGNET
DEE
VACUUM
CHAMBER
MAGNET
POLE
CONCRETE
SHIELDING
TARGET
"B"
Θ
10 FEET
[redacted]
CAVE

FIGURE 1