[11] P. Stähelin, Helv. Phys. Acta, **26**, 691 (1953).
[12] Kington, Bair, and Willard (private communication).
[13] C. P. Browne, Phys. Rev. **95**, 860 (1954).
[14] Endt, Enge, Haffner, and Buechner, Phys. Rev. **87**, 27 (1952).
[15] Simanton, Rightmire, Long, and Kohman, Phys. Rev. **96**, 1711 (1954), have successfully isolated long-lived aluminum ($T_{\frac{1}{2}}$ estimated to be about 10^6 years) from a deuteron bombardment of natural magnesium.

Slowing Down of Polarized Protons*

E. Heiberg, U. Kruse, J. Marshall, L. Marshall, and F. Solmitz
Institute for Nuclear Studies, The University of Chicago, Chicago, Illinois
(Received October 20, 1954)

Several mechanisms for depolarization of protons as they are slowed down in matter have been discussed by Wolfenstein,[1] who concludes that these are ineffective. Furthermore the additional depolarizing processes which we have been able to think of do not promise to be larger. Nevertheless an experimental knowledge of depolarization effects is necessary in the interpretation of many experiments. To this end we have degraded the energy of a polarized proton beam in several different substances.

A 425-Mev 54 percent polarized proton beam was used, produced by scattering the 435-Mev average energy circulating protons elastically at 14° from a Be target in the cyclotron. The polarization of the external proton beam so produced was determined by measuring the asymmetry of elastic scattering from Be at the same angle. In addition, the asymmetries of elastic scattering at 20° and at 30° were measured in a geometry subsequently used to measure asymmetries for the beam degraded in energy.

Next the beam was degraded to E' in paraffin, in C, in Cu, and in Pb. The asymmetry of elastic scattering of the degraded beam by beryllium was again measured at 20° and at 30°. The geometry was such that no protons scattered by more than 2.2° in the slowing down material could reach the Be. In passing through the 2-inch thick Be scatterer, the mean energy of the beam was still further reduced from E' to E. The emergent energy E was determined by range measurement in Cu.

Table I. Proton polarization *versus* energy attenuation.

Average energy of degraded beam Mev	Attenuating material	Percent asymmetry of elastic scattering (thickness of Cu filter given in parentheses) 20°		30°	
425[a]	None	63.2±9.3	(5.25 in.)	6.7±9.5	(5.25 in.)
		48.7±3.7	(5 in.)		
240	15.25 in. CH_2	50.0±1.6	(2.25 in.)	13.0±4.3	(2.25 in.)
	10 in. C	50.0±1.8		11.2±5.2	
	2.311 in. Cu	46.5±2.2		−4.8±5.4	
	2.378 in. Pb	46.8±2.6		−7.0±8.5	
	10 in. C	57.0±2.8	(2.75 in.)	21.9±13.0	(2.75 in.)
186	12 in. CH_2 + 10 in. C	64 ±8	(1 in.)	33 ±5	(1 in.)
~115	12 in. CH_2 + 14 in. C	35.8±3.6	(½ in.)	23.3±10.3	(½ in.)

[a] Initial polarization of 425-Mev beam =53.6±1.3 percent.

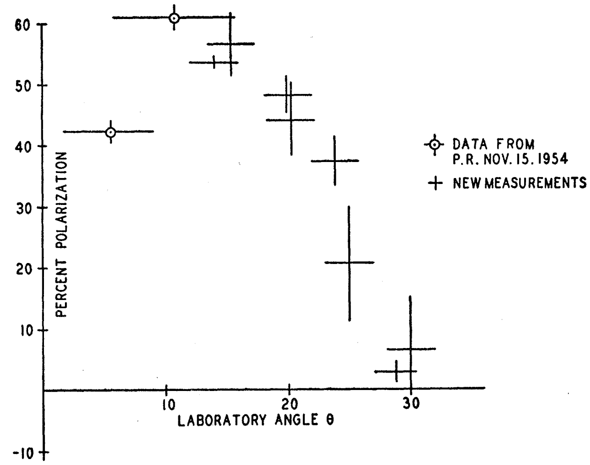

Fig. 1. Polarization of 425-Mev protons effected by elastic scattering on Be plotted as a function of laboratory angle of scattering.

The counter telescopes which measured the scattered protons were provided with copper filters such that quasi-nucleon-scattered protons could not produce a coincidence count. For the filter, that thickness of copper was chosen for which the range curve had dropped to about two thirds of the distance down from the "knee." In Table I are given the effective energy E, the thicknesses of the various attenuators, and the corresponding asymmetries of elastic scattering measured at the two laboratory angles.

In addition we have measured, with considerably better statistical accuracy and angular definition than previously,[2] the polarization of 425-Mev protons scattered elastically from Be and find the dependence shown in Fig. 1. It is similar to that known for Be,[2] C,[3] and He^3 at 310 Mev.

The asymmetries are practically unaffected by degradation of proton energy from 430 to 150 Mev regardless of Z and of nuclear spin of the attenuator. The slight increase in asymmetry with decreasing proton energy we ascribe to the fact that the elastic diffraction pattern is wider at lower energy and therefore the polarization curves (corresponding to Fig. 1) are wider.

In principle the polarization of the protons degraded from 425 to 240 Mev can be computed from the asymmetry measured at 240 Mev shown in Table I, together with the polarization by elastic scattering for Be at 20° and 240 Mev. Instead we use (50±10) percent measured[2] at 310 Mev and 20° for C, and compute for the polarization of protons degraded from 425 to 240 Mev, $P=\frac{1}{2}(50\pm 2)/(50\pm 10)=50\pm 10$ percent. This number we compare with the polarization of 53.6±1.3 percent measured for the 425-Mev beam. One sees that within the error no depolarization has occurred.

Similarly, using the corresponding asymmetry in Table I together with the elastic polarization measured for carbon at 20° and 140 Mev, 78±10 percent,[4] we compute for the polarization of the beam degraded to 186 Mev, $P=\frac{1}{2}(64\pm8)/(78\pm10)=41\pm7$ percent, which is not meaningfully different from the polarization of the 425-Mev beam.

We do not compute polarizations at 30° because at this angle probably equal numbers of elastically and inelastically scattered protons reach the counters.

For the proton beam degraded to ∼115 Mev, only protons of energy more than 100 Mev were measured. Range measurement showed that 60 percent of these protons had energy between 100 and 120 Mev, the remainder having somewhat higher energies. We interpret the low measured asymmetry as due to a decreased ability of elastic scattering to polarize below 150 Mev.

This result is anticipated by the elastic scattering asymmetry of 6±2 percent measured[5] near 70 Mev for Be at 20°, and by a decreased polarization observed at Harwell[6] below 140 Mev.

The present results show that for this energy range no small-angle interactions effect depolarization within the accuracy of these measurements.

* Research supported by a joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

[1] L. Wolfenstein, Phys. Rev. **75**, 1664 (1949).
[2] de Carvalho, Marshall, and Marshall, Phys. Rev. **96**, 1081 (1954).
[3] Chamberlain, Segrè, Tripp, Wiegand, and Ypsilantis, Phys. Rev. **96**, 807 (1954).
[4] J. M. Dixon and D. C. Salter, Nature **173**, 946 (1954).
[5] Karl Strauch, Bull. Am. Phys. Soc. **29**, No. **7**, 19 (1954).
[6] N. F. Ramsey (private communication via U. Kruse).