Figure 9 is a plot of the center-of-mass cross section in barns per steradian *vs* the center-of-mass scattering angle for the five highest laboratory energies of incident protons. The cross sections obtained from counting scattered protons are plotted as circles, those from the recoil tritons as squares. The ordinate for each higher curve has been raised by 0.05 barn per steradian in order that the points may be seen more clearly. The scale along the ordinate axis refers to the 3.50-Mev points. The zeros for the points at the lower energies are shown at the right of the graph. The negative curvature at the backward angles in the curve for the 2.74-Mev data is probably not significant.

It is a pleasure to express our appreciation to Professor J. H. Williams for suggesting this problem and for his advice throughout the course of this work. We should also like to thank the other members of the van de graaff group, Dr. G. R. Keepin, Dr. J. M. Blair, and Messrs. M. Fulk, T. F. Stratton, and J. L. Yarnell for their help in taking data. Mr. Rudolph Thorness made significant contributions to the design of the scattering chamber.

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Stars in Photographic Emulsions Initiated by Protons

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A study has been made of stars in photographic emulsions initiated by protons from the 184-inch Berkeley cyclotron. Ilford G-5 emulsions were exposed to the deflected proton beam with various Al absorbers interposed to obtain protons of various energies. Both the average number of prongs per star and the cross section for star production were found to increase with increasing proton energy.

I. INTRODUCTION

A STUDY has been made of stars in photographic emulsions initiated by protons from the 184-inch Berkeley cyclotron. Stars initiated by deuterons have been studied by Gardner and Peterson,[1] while stars initiated by alpha-particles have been studied by Gardner;[2] further work on them is being carried out by Bowker.

II. PROCEDURE

The present study differs from the previous ones in that electron-sensitive (Ilford G-5) plates were used. If plates of lower sensitivity are used, high energy star prongs will not be seen, and stars containing high energy prongs only will be completely missed. The electron-sensitive plates have the further advantage of recording the tracks of the high energy protons which initiate the stars. This enables one to find the cross section for star production.

It is desirable to obtain a uniform yet fairly light exposure of the plates. About 20 protons per 100-micron field of view was found to be convenient. Such an exposure could be made by dropping the plates through the deflected proton beam of the 184-proton cyclotron with the emulsion parallel to the beam so that the protons tracks are parallel to the emulsion surface. Although the energy of protons in the deflected beam is about 345 Mev, energies as low as 95 Mev were obtained by placing Al absorbers in front of the plates. The proper thicknesses of Al were calculated from the data on the range of protons in Al given by Smith.[3]

TABLE I. Energy distribution of prongs from stars.

Number of prongs \ Energy (Mev)	95	115	135	155	175	195	220	245	295	340
2	18	24	57	43	46	47	55	22	18	34
3	5	20	27	62	43	41	59	29	30	72
4	6	4	21	34	32	32	45	33	25	56
5	2	4	11	18	12	16	28	22	24	50
6	—	1	2	2	4	2	4	2	6	23
7	—	—	—	1	—	—	1	4	4	3
8	—	—	—	—	—	—	—	—	—	2
Total	31	53	118	160	137	138	191	112	107	240
Length of track (m)	50.0	60.4	112.3	179.6	144.7	149.0	169.8	90.6	80.6	175.0

[1] E. Gardner and V. Peterson, Phys. Rev. **75**, 364 (1949).
[2] E. Gardner, Phys. Rev. **75**, 376 (1949).
[3] J. H. Smith, Phys. Rev. **71**, 32 (1947).

The plates were scanned with a magnification of 450 and the position and number of prongs recorded for all stars of two or more prongs. It was felt that one-prong stars could not be unambiguously distinguished from random single track background. The results are summarized in Table I.

A plot of the average number of star prongs as a function of proton energy is given in Fig. 1. The vertical extent of the blocks is the standard error owing to the limited number of events. The horizontal extent of the blocks is an estimate of the energy spread of the protons used. The energy spread is due to three causes: the energy spread of the proton beam, the straggling in energy loss in the Al absorbers, and the energy loss in that part of the plate scanned. Three Mev appears to be a good estimate of the half-width of the energy spread of the deflected proton beam. The straggling of energy loss in the Al absorbers was calculated with the aid of formulas given by Livingston and Bethe[4] and was found to amount to only about 2 Mev for the thickest absorber used. The half-width of energy spread

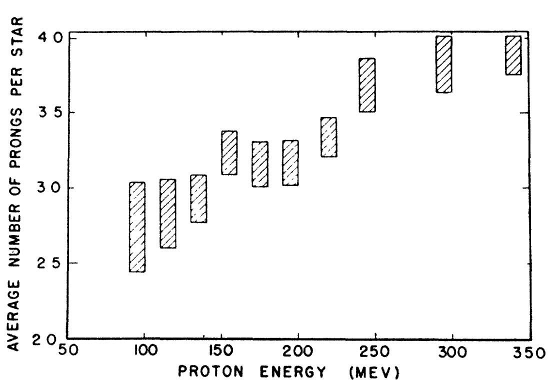

FIG. 1. Plot of average number of star prongs *vs* proton energy.

because of energy loss in the plate was limited to about 4 Mev. This was accomplished at the expense of scanning smaller areas at the lower energies. From these figures it would appear that 10 Mev is a fair estimate of the energy spread of the protons for all the energies examined.

The number of stars divided by the total length of proton track gives the mean free path for the production of stars of two or more prongs. The total length of proton track was found by counting track sections in a field of view in sample areas. The number of sections multiplied by the diameter of the field of view gives the total length of track in that sample area. About 100 sample areas were examined on each plate. The cross section can be found from the mean free path with the aid of data on the composition of the emulsion given by Ilford. These data are shown in Table II.

The number of atoms per cm^3 of emulsion excluding the H was used to calculate the cross section. A proton colliding with a H atom would give proton-proton scattering rather than a star. A few examples of proton-proton scattering were found and were easily distinguished from two-pronged stars. The cross section per atom for the production of stars of two or more prongs is shown as a function of energy in Fig. 2. Scales showing the mean free path in cm of emulsion and g/cm^2 of emulsion are also given. The horizontal and vertical extent of the blocks have the same significance as they had previously.

These cross sections are in good agreement with those found for alpha-particles by Gardner.[2] Gardner's cross

TABLE II. Composition of Ilford G-5 emulsions.

	Density (g/cm^3)	Molal fraction/cm^3
Total	3.907	0.1345
Total excluding H	3.851	0.0789

section *vs* energy curve showed a maximum of nearly 0.3 barn, at an alpha-particle energy of about 150 Mev, and fell off to about 0.2 barn at the maximum energy used, 200 Mev. This decrease of cross section with increase of energy may be due to the fact that Gardner used Eastman NTA emulsions for his study. These plates are less sensitive and would not record stars which had no low energy prongs. Such a star is more likely to be produced at higher energies of the bombarding particle.

At the highest energy studied, the mean free path found in this work is about twice the value of the mean

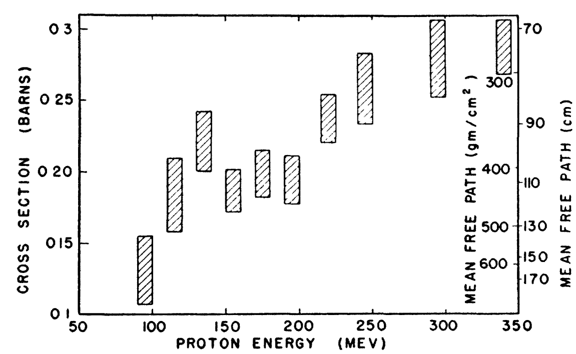

FIG. 2. Plot of cross section per atom for production of stars of 2 or more prongs *vs* proton energy.

free path of primary cosmic rays, presumably very high energy protons. Thus, one is lead to expect that the cross section for star production will continue to increase at energies above 350 Mev.

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[4] M. S. Livingston and H. A. Bethe, Revs. Modern Phys. **9**, 245 (1937).