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Stars in Photographic Emulsions Initated by Deuterons Part I. Experimental

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STARS IN PHOTOGRAPHIC EMULSIONS INITIATED BY DEUTERONS

PART I. EXPERIMENTAL

By

Eugene Gardner and Vincent Peterson

Radiation Laboratory, Department of Physics

University of California

January 5, 1948

Abstract

Photographic plates have been bombarded with deuterons in the 184" Berkeley cyclotron, and a group of 1200 stars in the emulsion has been studied. The group included 300 stars at each of the following energies: 35 Mev, 90 Mev, 130 Mev, and 190 Mev. At each of these energies the average number of prongs per star was close to 3.0. About three times as many prongs were observed in the forward direction of the beam as in the backward direction. The study was made with desensitized plates, which do not show tracks of high energy protons. The results are to be interpreted as including all alpha particles and heavier nuclear fragments but only the lower energy protons.

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STARS IN PHOTOGRAPHIC EMULSIONS INITIATED BY DEUTERONS
PART I. EXPERIMENTAL

By Eugene Gardner and Vincent Peterson

To be published in the Physical Review

January 5, 1948

STARS IN PHOTOGRAPHIC EMULSIONS INITIATED BY DEUTERONS

PART I. EXPERIMENTAL[1]

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1. Introduction

Deuterons and alpha particles accelerated by the 184" Berkeley cyclotron[2] are found to produce stars in photographic plates which are similar to stars produced by cosmic rays. For individual stars initiated by ~~high energy particles it is often impossible to find out, for any given star, what type of nucleus is responsible for the disintegration~~ deuterons from the cyclotron, we have not been able to tell with any assurance what type of nucleus is being disintegrated. Moreover, we do not know how many neutrons are given off or in which directions, so it is not possible to make a momentum or an energy balance. Thus it appeared that a detailed study of individual stars would not yield results which could be interpreted very easily. It was pointed out by Professor Robert Serber and Mr. Wendell Horning that experimental observations of large numbers of stars would yield statistical results which could be compared with theoretical predictions. The present paper reports the results of an experimental study of the number of prongs (i.e., the number of tracks making up the star) and the direction of the prongs with respect to the direction of the beam. The accompanying paper of Horning and Baumhoff gives a comparison of these experimental results with theoretical predictions.

2. Experimental Procedure

The plates used in this study were bombarded before the deflector of the 184" cyclotron was in operation, and the only method of exposure to deuterons was with the circulating beam. Now that the deflector is in operation[3], the circulating beam will probably be superseded by the deflected beam for bombarding photographic plates. The method of exposing plates to the circulating beam is shown in Fig. 1. The plate is wrapped in black paper and is mounted on the probe in a position such that the plane of the emulsion is approximately tangent to the deuteron trajectories. The deuterons strike the edge of the emulsion as shown in Fig. 2. A bombardment with deuterons of any energy up to the maximum available from the cyclotron can be obtained by placing the plates at the appropriate radius. It is assumed that stars which are found near the edge where the beam first strikes the plate were initiated by deuterons of the energy of the circulating beam at the radius at which the plate was exposed. The exposure required is small, and one of the problems is to make the circulating beam small enough. The cyclotron normally operates with a pulsed arc ion source, but we found that even one pulse gives too many deuterons. The plates used in the present study were exposed without an arc pulse; the arc filament was left on, and the r.f. was turned on for about half a second. The number of deuterons accelerated was controlled by varying the dee voltage.

The photographic plates used were Ilford Nuclear Research plates[4,5], type C.1, with an emulsion thickness of 100 microns. The chemical composition, as given by Ilford Limited, is shown in Table I. The C.1 plates are desensitized so that lightly ionizing particles do not make recognizable tracks. In this study the complete tracks of the initiating deuterons could just be seen at the lowest energy (35 Mev) but not at higher energies. Desensitization is an advantage because it permits a heavier exposure than would be possible with plates which show the tracks of the initiating particles. With the C.1 plates we were able to use deuteron intensities high enough to obtain useful plates with star densities as high as 10 stars per mm^2. In star studies using plates which render the tracks of the initiating particles visible, it is necessary to reduce this number to a factor of perhaps a hundred. Desensitization is also a disadvantage, however, since lightly ionizing particles from the stars will not show recognizable tracks. It is hard to give a definite value for the proton energy below which a proton track will always be visible. The possibility of seeing a track depends on the background of developed grains in the plate and on the length of track which lies in the emulsion. Proton tracks of length corresponding to an energy of 10 Mev are heavy enough so that it seems unlikely that we would miss tracks of this energy or lower. The length of a 10 Mev proton track, as given by Lattes, Fowler, and Cuer[6], is 560 microns. From the fact that deuterons can just be seen at 35 Mev but not at higher energies, we conclude that we could not see proton tracks of energy higher than about 17 Mev. In the region between 10 and 17 Mev we might see some prongs and not see others, depending on the background of developed grains and the length of track which lies in the emulsion. The results of this study of star prongs should be interpreted as including all alpha particles and heavier nuclear fragments but only the lower energy protons.

A group of stars initiated by deuterons of energy 190 Mev is shown in Fig. 3. Stars with various numbers of prongs are shown, but there has been no attempt to make the relative number of each type of star correspond to the statistical data. The number of long prongs shown is larger than would be expected in random sampling!

Table I. Chemical Composition of Ilford Nuclear Research Plates

Element	Weight (Grams per cc of Emulsion)
Ag	~~1.87~~ 1.85
Br	~~1.36~~ 1.34
I	0.053 0.052
C	~~0.33~~ 0.272
H	~~0.056~~ 0.056
O	~~0.24~~ 0.266
S	~~0.014~~ 0.010
N	~~0.083~~ 0.067
Ca, P, Cr, Si, Na	Traces

3. Experimental Results

The study included about 300 stars at each of four deuteron bombarding energies: 35 Mev, 90 Mev, 130 Mev, and 190 Mev. Several plates at each energy were viewed under the microscope, and sketches were made of the stars observed. All stars encountered in a scanning area near the incident edge of the plate were included, except for stars originating very near the emulsion surface. Data were tabulated at each energy for:

(a) number of prongs per star,

(b) angular distribution of star prongs, and

(c) average prong length of star prongs ending in the emulsion.

The number of stars having 2 prongs, 3 prongs, etc. are tabulated in Table II and plotted in Fig. 4. Each incident deuteron energy is computed from the radius in the cyclotron at which the plates were bombarded, with a small energy correction for the average distance from the edge of the plate to the point at which the stars were observed. The probable error of the energy measurement is of the order of $\pm$ 5 Mev. There is some uncertainty in the number of 2-prong stars, since it is often impossible to tell whether an event is a 2-prong star or a deflection in a single track. When it is reasonably clear from the grain densities of the tracks, or from other considerations, that the event is a 2-prong star, it is listed as "probable". If it is impossible to tell whether it is a star or a deflection it is listed as "questionable".

Table II. Number of Stars of a Given Number of Prongs For Various Incident Deuteron Energies

Type of Star	Number of Stars			
	35 Mev	90 Mev	130 Mev	190 Mev
2-Prong ("probable")	60	63	41	59
2-Prong ("questionable")	27	44	60	40
3-Prong	155	153	121	122
4-Prong	56	52	68	71
5-Prong	2	9	8	10
6-Prong	0	1	3	0
All types	300	322	301	302

In some cases it is clear that the event is a deflection of a single track, and these cases do not appear in the tabulation at all. From Table II it is seen that the average number of prongs per star is close to 3.0 for each of the energies studied.

When the stars are formed in the emulsion the star prongs can, of course, take any direction in three dimensional space. The emulsion shrinks when the plates are developed, and the stars are compressed toward a plane. As the stars are viewed under the microscope, one sees essentially the projection of the stars on a plane. The analysis of the angular distribution which we give does not refer to the three-dimensional stars as they are formed in the emulsion, but to the projections on a plane as they are seen through the microscope. The field of view of the microscope was divided into 60° sectors, and a tabulation was made of the numbers of prongs in the various sectors. The results are given in Table III and in

Fig. 5. The sector in the forward direction of the beam extends from -30° to -30°, where the beam direction is taken as 0°. In cases where there are two sectors whose centers make the same angle with the beam direction, the total number of prongs observed in both sectors is tabulated in Table III, but the value plotted in Fig. 5 is the average for one sector. There are about three times as many prongs in the three forward sectors as in the three backward sectors.

No systematic attempt was made to identify the prong particles. However, some of the prongs had a change in grain spacing such that they were tentatively identified by inspection as proton tracks. In order to give an order of magnitude for the lengths of the star prongs for the various energies of the initiating deuterons, we have listed in Table IV the per cent of prongs ending in the emulsion and the observed average prong lengths for tracks which ended in the emulsion. This does not give a true measure of the average prong length for two reasons: (1) the longer prongs have a greater probability of leaving the emulsion, and (2) the length as seen through the microscope is the prong length projected on a plane. Both of these factors tend to make the values given in Table IV too small. The energy associated with a proton track or an alpha particle track of given length can be found from the range-energy relationships given by Lattes, Fowler, and Cuer[6]. For example, the energy of a track of length 40 microns is given as 2 Mev if the particle is a proton, or about four times this energy if it is an alpha particle.

Table III. Angular Distribution of Star Prongs

For Various Incident Deuteron Energies

Angular Range	Angle from Beam Direction to Center of Sector	Number of Star Prongs 35 Mev	90 Mev	130 Mev	190 Mev
-30° to $+30^{\circ}$	0°	326	335	295	267
$+30^{\circ}$ to $+90^{\circ}$ and -30° to -90°	60°	385	366	339	388
$+90^{\circ}$ to $+150^{\circ}$ and -90° to -150°	120°	128	166	184	187
$+150^{\circ}$ to -150°	180°	42	55	58	66
	Total:	881	922	876	908

Table IV. Average Observed Projected Track Lengths of Star Prongs

Ending in the Emulsion

	35 Mev	90 Mev	130 Mev	190 Mev
Per cent of Prongs Ending in the Emulsion	75	65	56	62
Average Observed Prong Length ~~(Microns)~~ from Star Prongs Ending in the Emulsion (Microns)	20	32	35	42

4. Acknowledgements

The authors wish to express their appreciation to Professor Ernest O. Lawrence for his continued interest in this study. We are indebted to Professor R. L. Thornton and Professor E. M. McMillan for helpful discussions. We also wish to thank Mr. A. J. Oliver for the preparation of Fig. 3, Mr. Duane Sewell and the cyclotron crew for bombarding the plates, and Mr. C. Waller of Ilford Limited for information regarding Ilford Nuclear Research Plates.

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[1] Reported at meetings of the American Physical Society, July 11-12, 1947, and January 2-3, 1948.

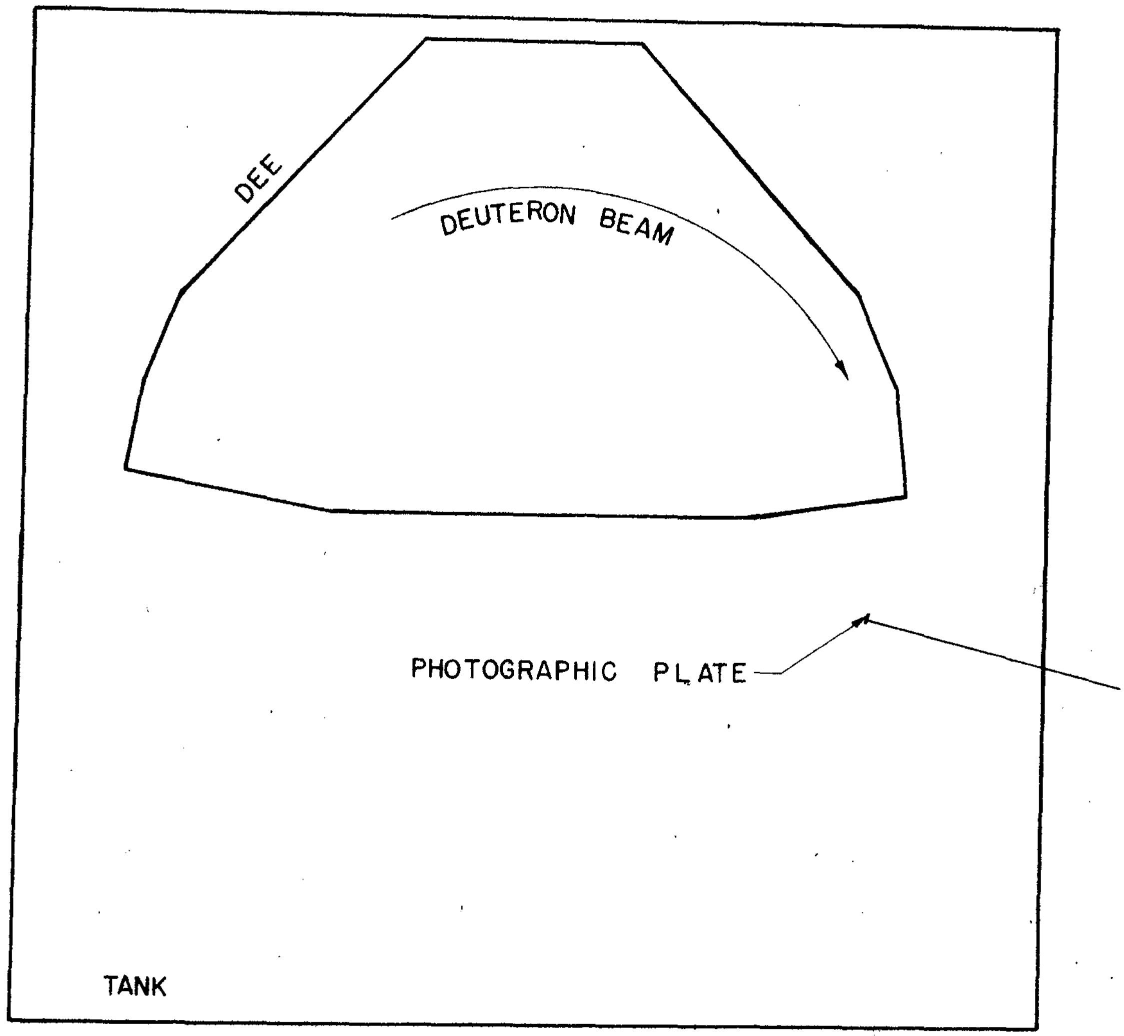
[2] W. M. Brobeck, E. O. Lawrence, et al., Phys. Rev. 71, 449 (1947)

[3] W. M. Powell, L. R. Henrich, Q. A. Kerns, D. C. Sewell, and R. L. Thornton. (To be published)

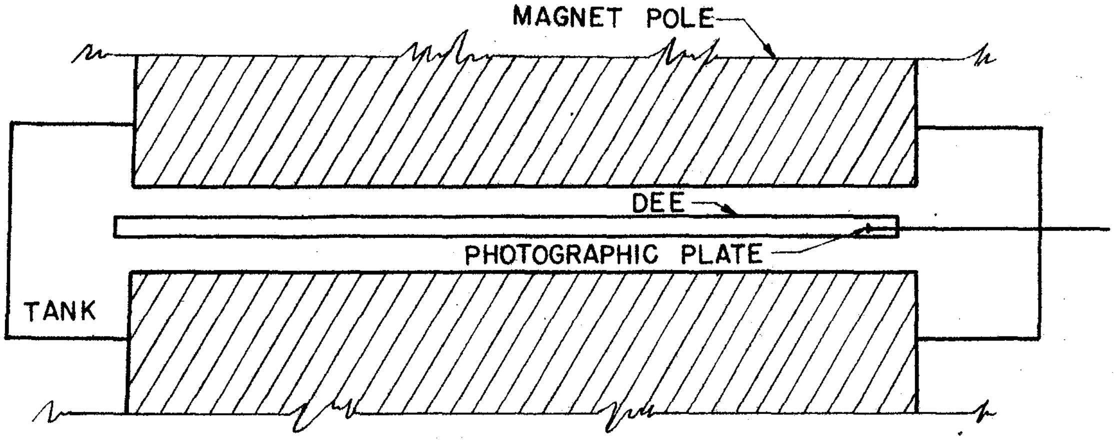
[4] Powell, Occhialini, Livesey, and Chilton. J. Sci. Instr. 23, 102 (1946)

[5] C. F. Powell and G. P. S. Occhialini, Nuclear Physics in Photographs. Clarendon Press, Oxford, 1947.

[6] C. M. G. Lattes, P. H. Fowler, and P. Cuer, Proc. Phys. Soc. 59, 883 (1947)



TOP VIEW



LOCATION OF PHOTOGRAPHIC PLATE FOR EXPOSURE TO CIRCULATING BEAM

Fig.1 Diagram of cyclotron showing position of photographic plate for bombardment by circulating beam.

FIG. 1

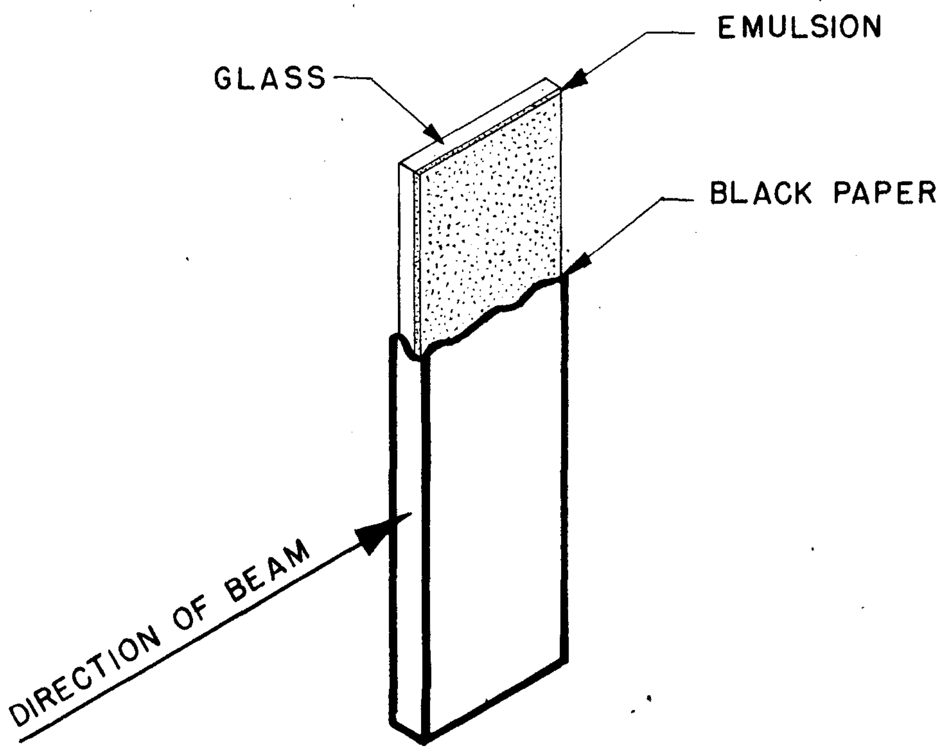


Fig. 2. Diagram of photographic plate showing direction in which beam strikes emulsion.


BEAM DIRECTION
0
0.1 mm

[illegible]

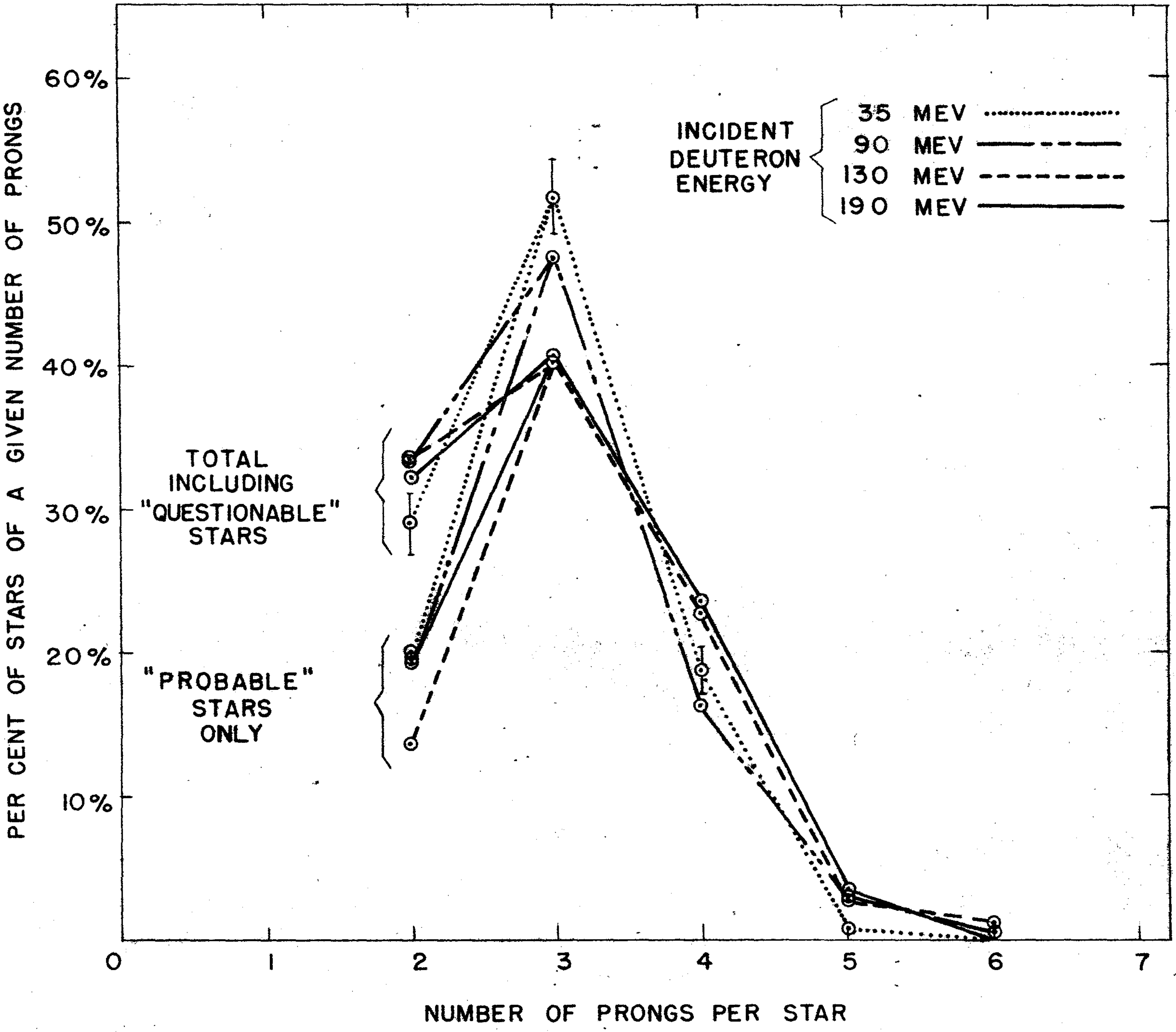


Fig. 4. Frequency distribution of various types of stars. Per cent of stars of a given number of prongs as a function of the number of prongs.

FIG 4

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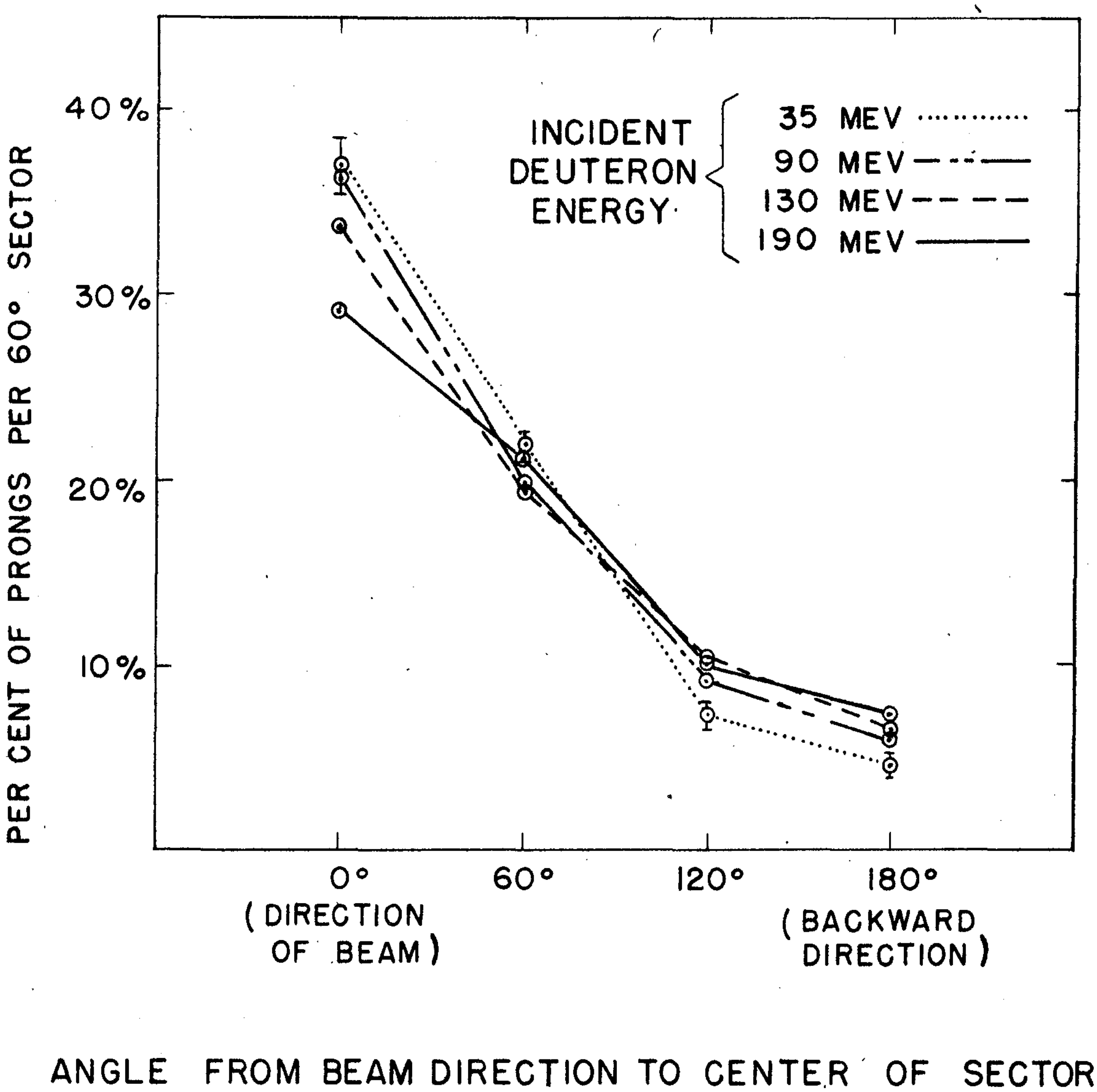

Fig. 5. Angular distribution of prongs. Per cent of prongs per 60° sector as a function of angular position of center of sector.