Table 1 Stars on the background plates developed on

29 January 1963.

Plate No. 1			Plate No. 2		
No. of prongs per star	No. of stars N	No. of stars with more than n prongs N > n	No. of prongs per star	No. of stars N	No. of stars with more than n prongs
2	54	1204	2	93	1195
3	653	529	3	664	532
4	443	86	4	459	93
5	73	11	5	81	12
6	5	6	6	4	0
7	2	4	7	2	0
8	2	2	8	3	3
9	0	2	9	1	2
10	1	1	10	1	1
11	0	1	11	1	0
12	1	0	12	0	0
Total No. of stars 1258			Total No. of stars 1252		

Table 2 Stars on the plate No.1 developed on 18 April 1953 under various thicknesses of absorbers.

No. of prongs per star n	Thickness of Absorbers (cm Pb.)											
	0		1		2		3		9		10	
	N	N>n	N	N>n	N	N>n	N	N>n	N	N>n	N	N>n
2	150	2037	[illegible]	[illegible]	[illegible]	[illegible]	140	[illegible]	130	[illegible]	[illegible]	[illegible]
3	1085	979	1070	934	1093	907	1085	[illegible]	986	[illegible]	[illegible]	[illegible]
4	815	[illegible]	740	196	797	190	700	359	749	[illegible]	[illegible]	[illegible]
5	247	27	135	10	142	8	134	9	130	21	[illegible]	[illegible]
6	8	9	8	10	2	5	0	5	7	9	9	9
7	3	6	0	10	0	5	5	2	1	[illegible]	0	9
8	1	5	3	7	2	3	1	1	1	7	[illegible]	7
9	2	3	2	6	0	3	0	1	1	[illegible]	[illegible]	3
10	1	2	1	5	0	5	1	0	3	[illegible]	[illegible]	[illegible]
11	0	2	2	2	1	2			1	[illegible]	1	2
12	0	2	0	[illegible]	1	1			0	[illegible]	[illegible]	1
13	0	2	1	2					0	[illegible]	0	1
14	0	2	0	2					1	1	0	1
15	1	1	0	2					1	0	0	1
16	0	1	1	1							10	0
17	1	0	0	1								
19			1	0								
24					1	0						
Total No. of Stars	2217		2150		2140		2064		2070		[illegible]	

Table 3 Stars on the plate No.2 developed on 16 April 1963 under various thicknesses of absorbers.

No. of prong per star n	Thickness of Absorbers (cm Pb.)											
	0		1		2		3		5		10	
	N	N>n	N	N>n	N	N>n	N	N>n	N	N>n	N	N>n
2	156	2023	134	2012	147	1981	127	1946	121	1906	118	1799
3	1090	933	1036	976	1021	960	1031	915	998	908	934	865
4	790	143	786	190	780	180	756	159	750	158	712	153
5	131	12	174	16	172	8	147	12	147	11	142	11
6	5	7	7	9	4	4	6	6	6	5	4	7
7	2	5	3	6	0	4	2	4	2	3	2	5
8	1	4	2	4	1	3	1	3	1	2	1	4
9	1	3	0	4	2	1	0	3	0	2	2	2
10	1	2	2	2	1	0	0	3	1	1	0	2
11	0	2	1	1			1	2	1	0	1	1
12	1	1	0	1			1	1			1	0
14	1	0					1	0				
17			1	0								
Total No.of Stars	2179		2146		2128		2073		2027		1917	

Table 4 Stars on the plate No. 3 developed on 25 April 1963 under various thicknesses of absorbers.

No. of prongs per star n	Thickness of Absorbers (cm. Pb.)											
	0*		1		2		3		5		10	
	N	N>n	N	N>n	N	N>n	N	N>n	N	N>n	N	N>n
2			140	2022	122	1977	124	1910	119	1919	107	2080
3			1042	900	1045	934	1016	893	906	995	974	970
4			795	124	764	270	774	126	765	169	701	169
5			273	11	150	12	111	13	158	11	137	12
6			6	9	9	5	7	3	7	4	6	[illegible]
7			2	5	1	4	9	5	2	2	1	2
8			1	2	2	2	1	2	1	1	2	[illegible]
9			1	1	1	1	0	2	1	[illegible]	1	2
10			0	1			1	1				
11			1	0								
14							1	0			1	1
16											1	0
18					1	0						
Total No. of Stars			2162		2099		2043		2019		1980	

* The plate was damaged during development.

Table 5 Average number of stars on the plates at various thicknesses of absorbers.

No. of prong per star n	Thickness of Absorbers (cm Pb.)						
	Developed on 29 Jan. 1965	Developed on 16 April 1965					
	0	0	1	2	3	9	10
2	52.0	253.0	168.0	256.3	259.7	222.0	214.0
3	649.5	1039.0	[illegible]	1052.3	1083.3	[illegible]	921.7
4	451.0	692.5	707.3	700.3	705.3	[illegible]	701.3
5	70.0	139.0	161.0	157.3	150.7	141.7	156.7
6	4.5	6.5	7.0	4.3	4.3	6.7	3.0
7	2.0	2.5	1.7	0.3	2.7	1.7	1.7
8	2.5	1.0	3.3	2.7	1.0	1.0	1.0
9	0.5	1.5	0.7	1.0	0.0	0.7	1.7
10	1.0	1.0	1.0	0.3	0.7	1.3	0.7
11	0.5	0.0	1.3	0.3	0.3	0.7	0.7
12	0.5	0.5	0.0	0.3	0.3	0.0	0.7

Table 6 Total number of stars observed on the plates, (excluding 2-prong stars)

Date of Development	Thickness of Absorbers (cm Pb.)	Total No. of Stars	Stars found in [illegible]	Average No. of Stars Found in [illegible]	Standard Deviation σ [illegible]	Relative Star Intensity
29 Jan.1963	0	2250 2252	Back-ground	1249	9.1	–
16April 1963	0	2217 2179	928 894	915	21.9	100.0
16April 1963	1	2150 2146 2102	909 902 927	912	21.0	99.6
16April 1963	2	2125 2120 2020	873 885 852	872	14.0	95.3
16April 1963	3	2015 2075 2056	839 825 831	831	22.7	90.7
16April 1963	5	1999 2027 2010	724 702 709	775	20.9	[illegible]
16April 1963	10	2030 1997 1986	609 672 675	[illegible]	21.0	69.0

Table 7 Stars formed in 70 days under various thicknesses of absorbers and the total rate of production of stars.

No. of prongs per star n	Thickness of Absorbers (cm Pb.)					
	0	1	2	3	5	10
2	95.0	95.0	[illegible].3	70.7	57.0	59.0
3	439.5	395.1	382.0	375.0	339.0	292.2
4	391.5	330.5	309.3	312.3	303.3	[illegible].3
5	81.0	85.0	79.3	52.7	63.7	[illegible]0.7
6	2.0	2.3	0.2	- 0.2	2.2	0.9

Thickness of Absorbers (cm Pb.)	Total No. of Stars formed in 70 days.	Star Rates in Stars per c.c. per day.
0	955	14.9± 0.5[illegible]
1	901	13.79± 0.4[illegible]
2	871	13.29± 0.43
3	810	12.4[illegible]± 0.21
5	775	11.0[illegible]± 0.4[illegible]
10	664	10.12± 0.39

Table 6 Number of stars with more than n-prongs at various thicknesses of absorbers.

No. of prongs per star n	Plate No.	Thickness of Absorber(cm Pb.)					
		0	1	2	3	5	10
2	1	677.0	755.0	730.0	757.0	672.0	503.0
	2	695.0	685.0	751.0	755.0	713.0	686.0
	3	*	652.0	757.0	722.0	729.0	[illegible]
	Mean	695.0	651.0	709.3	757.3	705.0	605.0
3	1	450.5	573.5	465.5	350.5	307.5	215.5
	2	392.5	425.5	429.5	377.5	307.5	275.5
	3	*	435.5	393.5	327.5	392.5	295.5
	Mean	425.5	422.0	450.5	365.5	301.2	282.0
4	1	77.5	57.5	68.5	49.5	66.5	66.5
	2	52.5	103.5	90.5	62.5	61.5	59.5
	3	*	57.5	60.5	35.5	72.5	75.5
	Mean	57.0	62.5	77.2	52.3	65.6	62.3

* The plate was damaged during development.

Table 9 Total number of stars observed on the plates, excluding 2-prong stars.

Date of Development	Thickness (cm. Pb) of Absorber	Total No. of Stars	Stars Formed in 78 Days	Average No. of Stars Formed in 78 Days	Standard Deviation σ (%)	Relative Star Intensity (%)
29 Jan. 1953	0	1186 1195	Unknown	1190	5.5	–
16 April 1953	0	2069 2023	877 831	853	31.1	100.0
16 April 1953	1	1989 2052 2022	794 822 [illegible]	[illegible]	[illegible]	[illegible]
16 April 1953	2	1900 1901 1977	720 721 [illegible]	[illegible]	[illegible]	[illegible]
16 April 1953	3	1929 1976 1982	754 756 782	757	17.2	[illegible]
16 April 1953	5	1839 1905 1919	679 716 729	730	20.5	[illegible]
16 April 1953	10	1779 1799 1816	589 609 626	608	25.3	[illegible]

Fig.1 Frequency distribution of stars with their prongs, at ground level, [illegible], latitude [illegible] N. on Ilford [illegible] plates [illegible] microns thick.

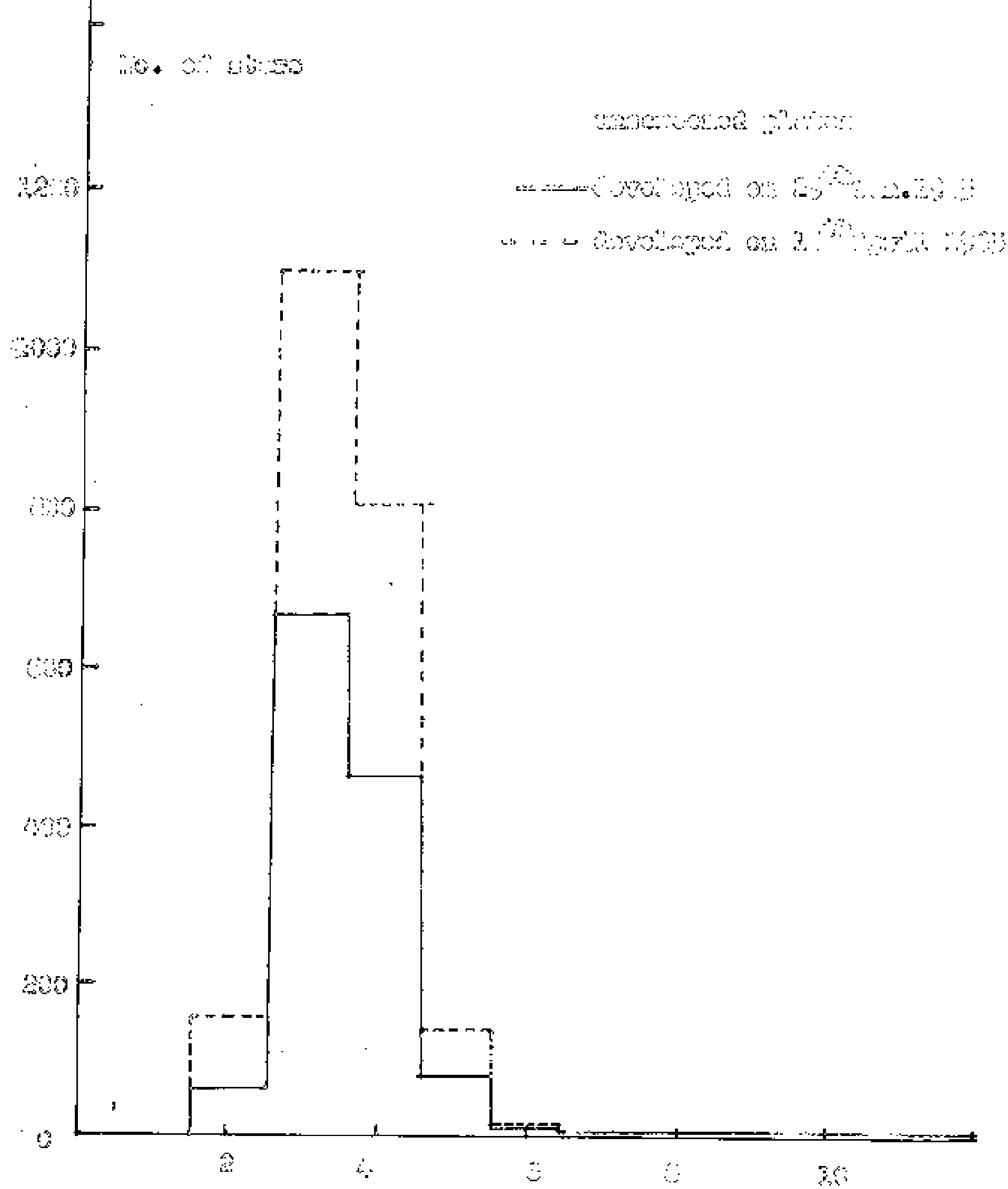


Fig.2 Size distribution of stars at ground level, Bangkok, Thailand, latitude 13° 46' N.

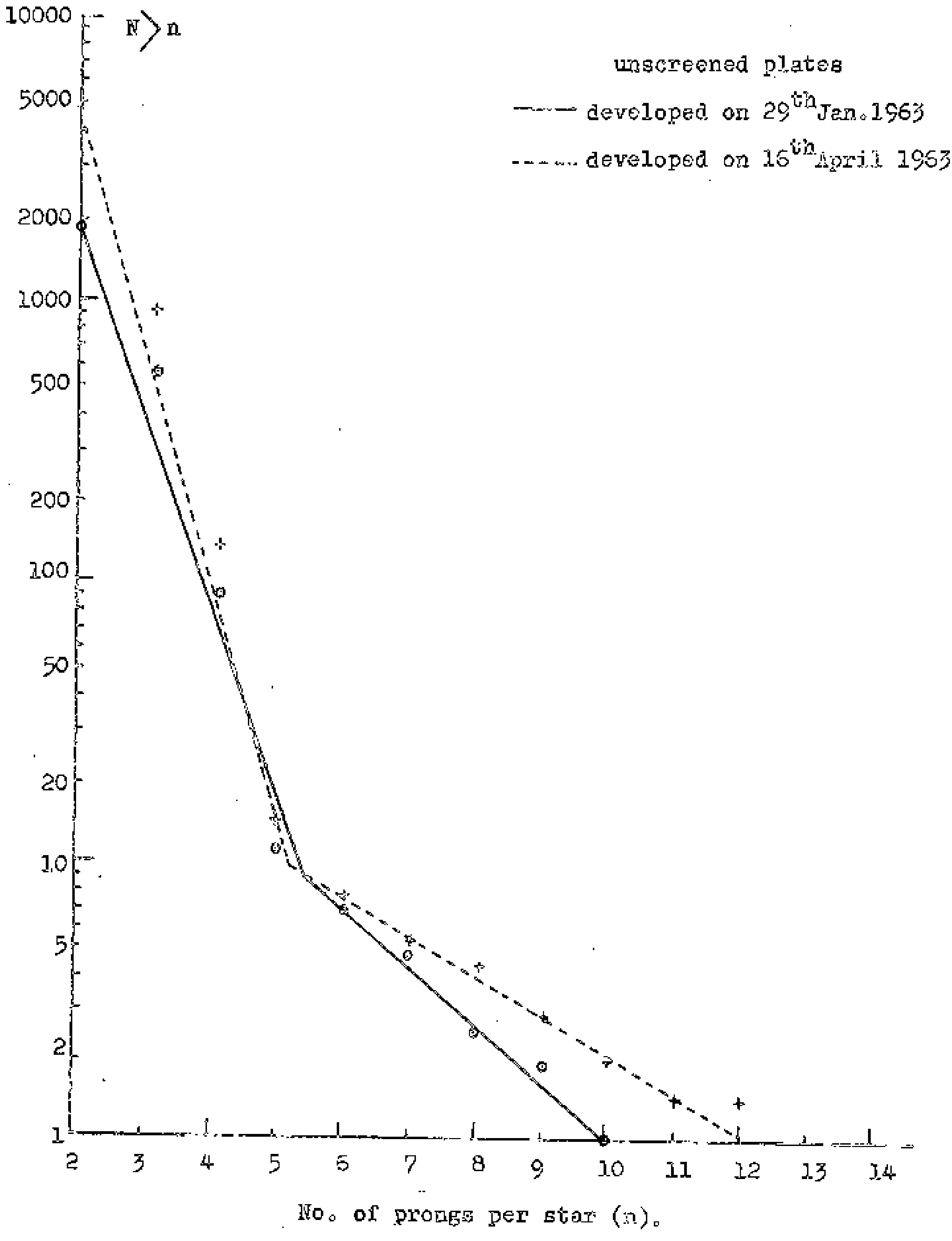


Fig. 3 Stars formed in 78 days under various thicknesses of absorbers.

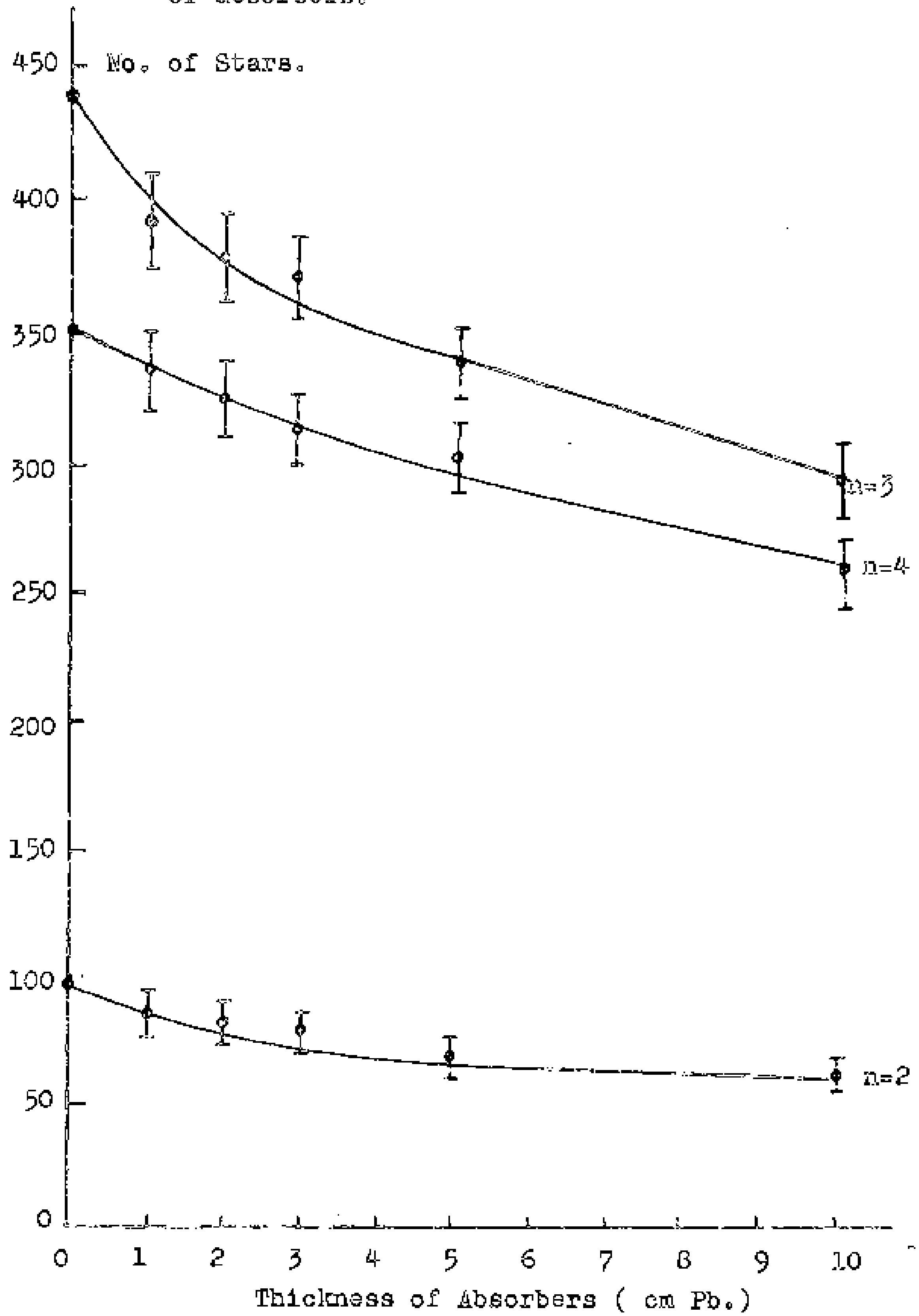


Fig.4 Absorption curve of the star intensity, in lead including 2-prong stars.

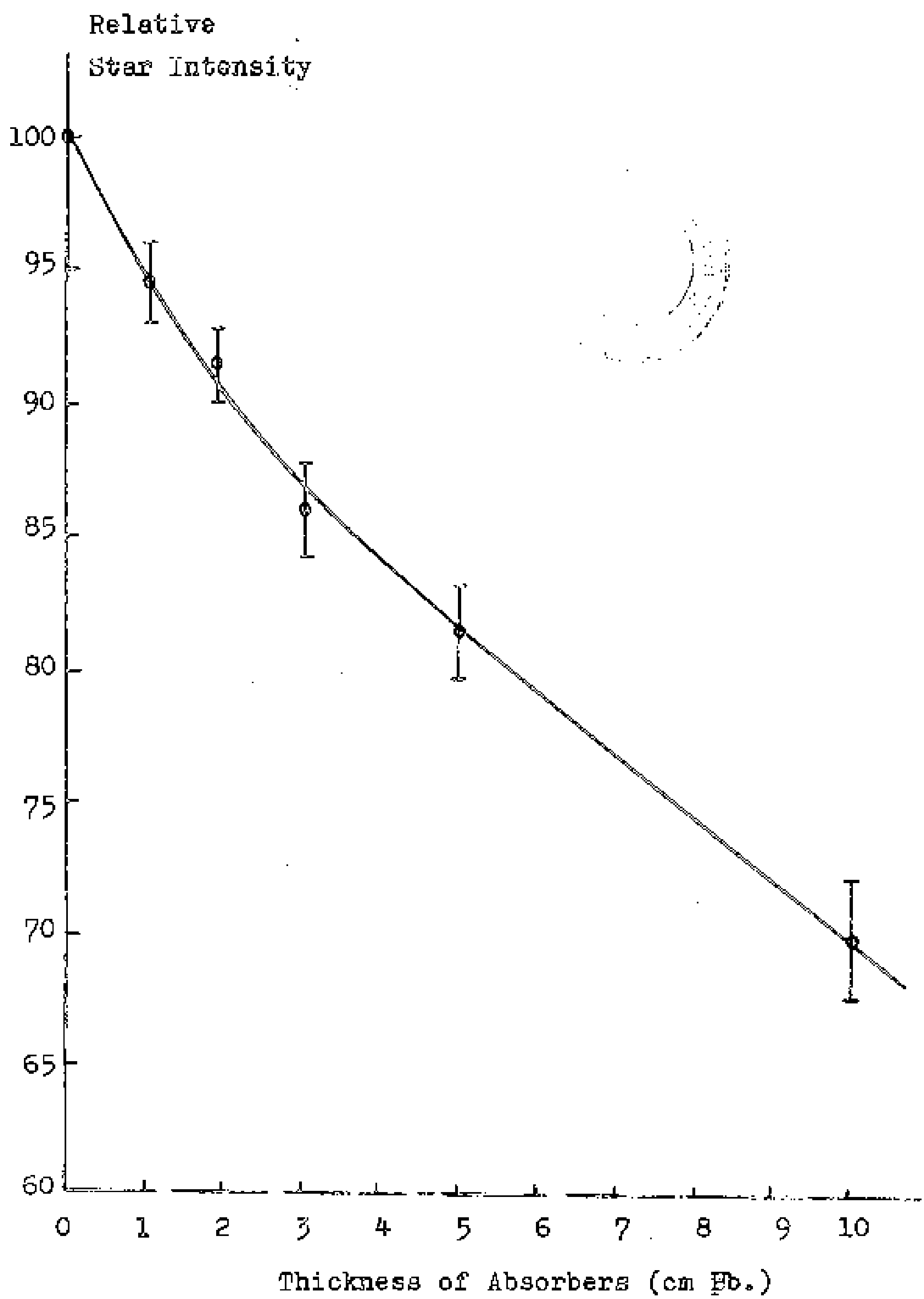


Fig. 5 The number of stars with more than n-prongs under various thicknesses of absorbers.

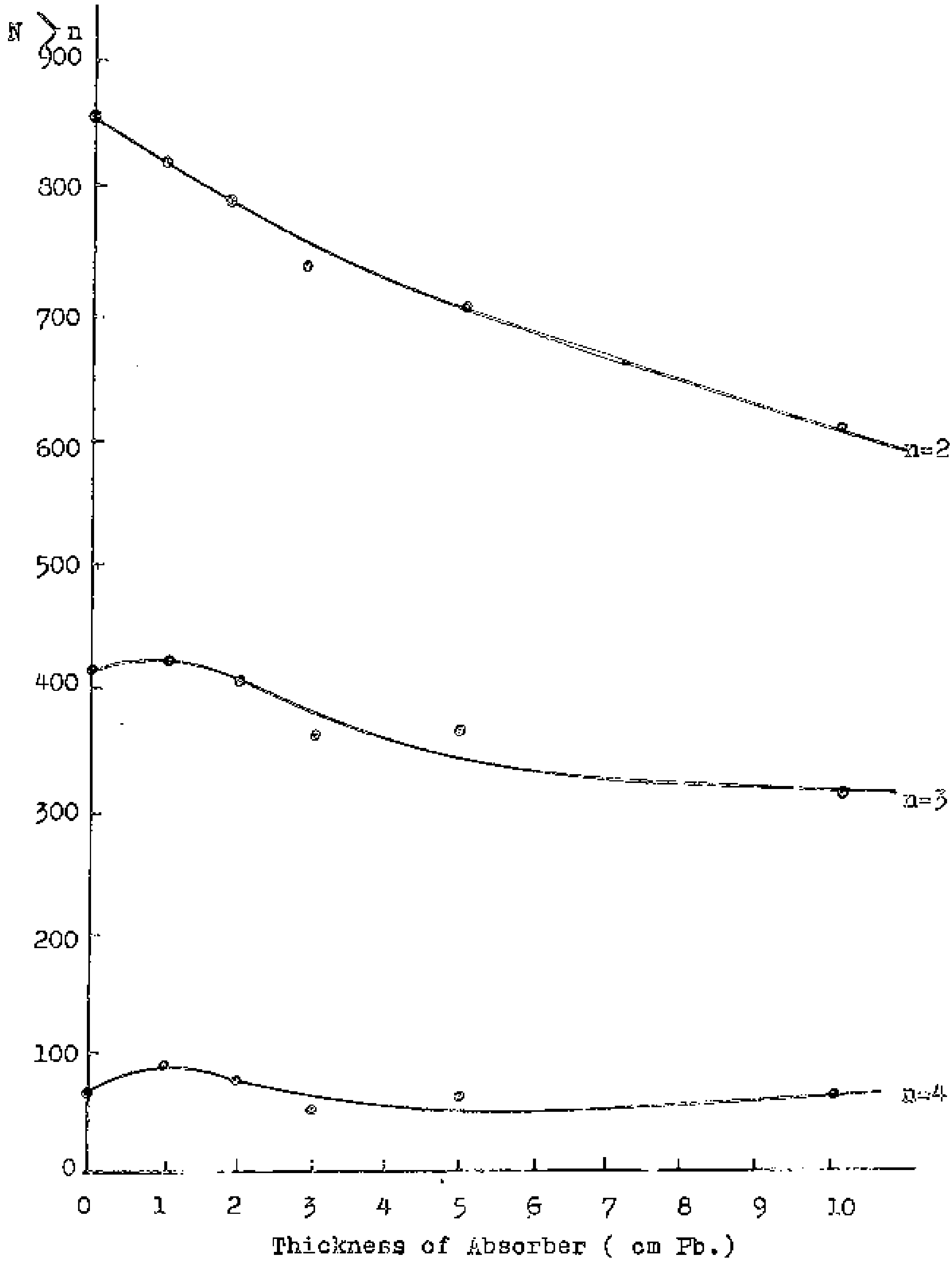
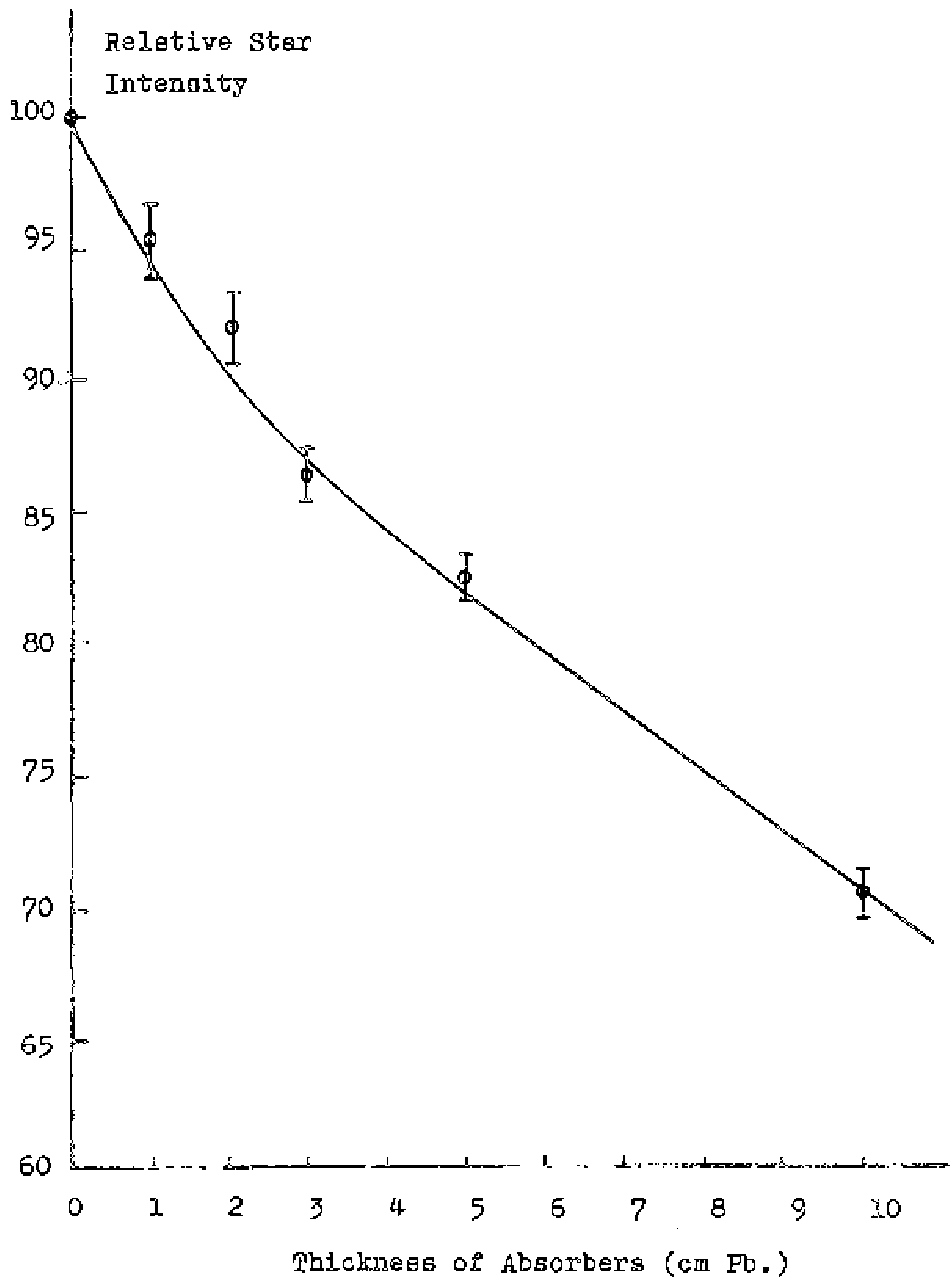


Fig.6 Absorption curve of the star intensity, in lead.

(2-prong stars are excluded)



CHAPTER VI

DISCUSSION OF RESULTS AND CONCLUSIONS

<u>Discussion of Results</u>

Our results show significantly that most of the stars formed in the emulsions, screened and unscreened plates, at ground level are 3-prong stars. These are similar to the results of earlier workers such as those described by [illegible], E.P.George and A.C.Jason(22) and J.[illegible] and S.[illegible]. These results show that the great part of cosmic ray components causing the formation of stars at ground level are **mostly** of low energies.

The results of Mason(20) showed that at ground level the particles responsible for the low energy stars are predominantly neutrons. These were in agreement with E.P. George and A.C.Jason (22). In recent years J.[illegible] and [illegible] have observed the ground level cosmic ray stars and the east-west asymmetry effect of the star producing components at the same place where this experiment was performed and showed that most of the components are neutrons.

At first we assumed that all of the stars were only caused by cosmic ray component and the intensity of this component in the atmosphere remained constant during this experiment.

By this way the absorption curve was shown in Fig.4, and by the method of least squares we obtained the absorption equation

$$N = 992.2 \exp(-X/20.4)$$

where N is the number of stars obtained at a thickness X in cm. The equation shows the absorption length of 322± 16 gm cm^{-2}.

By studying the components of nuclear emulsions, we know that salts of thorium and uranium were frequently incorporated in the early emulsions and usually responsible for the radioactive contamination shown in the emulsions. Most of the radioactive contamination stars are caused by the successive radioactive decay of an original atom of thorium and usually caused 2-prong stars. According to Powell(36), in the early investigations, they were mistaken by some observers for nuclear disintegrations produced by cosmic rays.

Many recent investigations, e.g., by E.P.George and A.J. Jason(22), by G.Bernardini and G. Cortini...(33), and by many others, the number of two prong stars were excluded in their investigations to avoid radioactive stars.

In our estimation of absorption curve, excluding two prong stars, we obtained the absorption curve shown in Fig.5, with the absorption equation

$$N = 842.0 \exp(-X/29.9)$$

The absorption length was 394.39± 10 gm cm^{-2} which is a little different from the one when the 2-prong stars are included.

A notation on the density of the lead bricks used in our experiment is that the density obtained by many measurement is 11.34 gm cm^{-3}. Other authors may used different values according to the purity of the lead they used. These values are very important for calculation of the absorption length in lead of the star producing component.

In Fig. 3 we can see that, the rate of production of 3- prong stars in every exposed plates is more than that of 2 or 4 prong stars. The rate of production of 4- prong stars is more than that of 2- prong stars. The maximum rate of production of stars is of 3-prong stars. These are in agreement with the other authors, notably of George and Jason(22).

Furthermore, the number of stars with more than 2,3 and 4 prongs under various thicknesses of absorbers, shown in Fig.5, is of different absorption curves. The absorption of stars with more than 3 and 4 prongs is very similar to that of the absorption of the hard component. This results support the evidence that the more energy the N- components have, the more prongs of the stars they caused. The number of the stars with more than 3-prongs is less than 1 per cent of the total stars which is too little in order to provide a suitable curve.

The graph shown in Fig.5 also shows the peaks of the curve $N > n=3$ and $N > n=4$. These can be interpreted in two different ways. First, some of the N-components travelling through 1 cm of lead were absorbed by the nuclei of the emulsions at resonant energy to cause the 4 and higher prong stars. Therefore the peaks are at 1 cm of lead thickness. The second interpretation is due to the multiplications of the components, which may be initiated from the nuclear disintegrations in lead. We have mentioned that most of the component are neutrons, and by consideration about the number of high energy stars on the unscreened plates which is very little, the multiplications should not occure. The other evidence to support this explanation is that we did not find any secondary stars in the emulsions.

Now, we shall consider the theoretical standard deviation of the mean, corresponding to the peak value at 1 cm thickness of lead and to the lower value at 0 cm of lead. The curve $N > n=3$ shows the peak value of [illegible] and the lower value at 0 cm of lead is [illegible]. The results obtained, however, show that the peaks are not high enough to give a clear picture of absorption. This may be due to the small number of stars formed at this part of the curve.

Conclusions.

From the above results the following conclusion may be made.

a) Most of the stars found in the emulsions, screened and unscreened plates, are 3-prong stars. The maximum rate of production of stars in the emulsions at various thicknesses of absorbers is also of 3-prong stars.

b) The rate of production of 4-prong stars is more than that of 5-prong stars in every thickness of absorbers. The total rate of production of stars is found to be decreased with the increasing of the absorber thicknesses.

c) The absorption equation of the total stars in the plates is $N=952.2 \exp(-X/80.6)$, with the absorption length of [illegible]±10 gm cm^{-2}.

d) The absorption equation of total stars, excluding 3-prong stars, is $N=641.8 \exp(-X/20.5)$, with the absorption length of 394.53±11 gm cm^{-2}.

e) The size distribution of the stars in the plates without absorbers at ground level, has the clear break between 5 and 6 prongs.

f) The absorption of many prong stars are different from that of few prong stars. The absorption curve of stars with more than 3 and 4 prongs is more similar to the absorption of the hard component, and the absorption of stars with less than 3-prongs is similar to that of the soft component.

APPENDIX

ABSORPTION EQUATION

The absorption equation may be expressed as $N = N_0 \, e^{-x/\lambda}$, where x is the thickness of absorber in gm cm^{-2}, λ is the absorption thickness. Taking logarithm on both sides, we have;

$$\log N = \log N_0 + \left(- \frac{1}{\lambda} \log e \right) x \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Equation(1) is the equation of straight line. On comparison with equation(1), we can write,

$$\begin{aligned} y_1 &= a + bx_1 \\ y_2 &= a + bx_2 \\ y_3 &= a + bx_3 \\ &\vdots \\ y_n &= a + bx_n \end{aligned} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Thus, we have two unknowns, i.e., a and b, from n observations. If $n=2$ we can solve for a and b easily. But when $n > 2$, the method to solve for a and b is different. Now, if S is the function of two unknowns a and b and is expressed as;

$$S = [y_1 - (a + bx_1)]^2 + [y_2 - (a + bx_2)]^2 + \ldots\ldots\ldots + [y_n - (a + bx_n)]^2$$

We shall minimise S

$$\frac{\partial S}{\partial a} = -2[y_1 - (a + bx_1)] - 2[y_2 - (a + bx_2)] - \ldots\ldots\ldots - 2[y_n - (a + bx_n)] = 0$$

$$\frac{\partial S}{\partial b} = -2x_1\left[y_1 - (a + bx_1)\right] - 2x_2\left[y_2 - (a + bx_2)\right] \ldots\ldots\ldots\ldots - 2x_n\left[y_n - (a + bx_n)\right] = 0$$

from which

$$na + (\Sigma x)b = \Sigma y \qquad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$
$$(\Sigma x)a + (\Sigma x^2)b = \Sigma xy$$

From equation (3) we have;

$$a = \frac{N_a}{D} \; ; \; b = \frac{N_b}{D} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

where

$$D = \begin{vmatrix} n & \Sigma x \\ \Sigma x & \Sigma x^2 \end{vmatrix} \; ; \; N_a = \begin{vmatrix} \Sigma y & \Sigma x \\ \Sigma xy & \Sigma x^2 \end{vmatrix} \; ; \; N_b = \begin{vmatrix} n & \Sigma y \\ \Sigma x & \Sigma xy \end{vmatrix} \qquad \ldots\ldots\ldots(5)$$

From equation (4) and (5) the value of the constant a and b and that the value of N, the absorption thickness, can be determined.

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