STARS AND SINGLE TRACKS IN NUCLEAR PLATES

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In March 1949, a series of balloon flight experiments was conducted from Madras, in which Ilford N.R. plates (B_2 and C_2, 50 μ) were exposed at altitudes up to 60,000 ft. In June 1949 a similar series was conducted from Bangalore, using Kodak N.T. 4 plates (200 μ), in which altitudes above 90,000 ft. were reached. Some plates from each batch were used as controls and developed along with the flight plates. The plates have now been partially examined, and the purpose of the present paper is to give a preliminary report of phenomena observed in the plates which appear to be of interest and importance.

All the plates examined show a population of short isolated tracks. In the preliminary stages of the examination of the plates we were struck by the apparent constancy in the length of these tracks, and by the fact that they often appeared in the vicinity of stars. Stars were frequently found with an isolated track visible in the same field of view. With some stars there were two such tracks and in two cases even three. It was therefore considered desirable to collect detailed statistics regarding the phenomenon, which has so far not been reported by other workers.

Some 50 sq. cm. of the plates has been examined under a medium power, in which about 1,200 isolated tracks have been recorded. The results shown in Table I are confined, however, to a total area of some 17 sq. cm. which has been examined in detail, using objectives of 60x with a N.A. of 0·90. Care has been taken to ensure that nothing of significance has been missed in this area. The actual measurements have all been made under oil.

Only those isolated tracks of which both ends are in the emulsion, and only those stars which have their point of origin in the emulsion, are included in the statistics. The stars are classified into 'large' and 'small'. Large stars are those with six or more prongs, or with one track exceeding 60 μ in length. These stars are almost certainly of cosmic ray origin, whereas the small stars may be due, in part, to radioactive contamination. The results for the four groups of plates are collected in Table I.

TABLE I

	Bangalore flight	Bangalore control	Madras flight	Madras control
Type of Emulsion	Kodak N.T. 4	Kodak N.T. 4	Ilford B_2	Ilford B_2
Thickness of Emulsion	200 μ	200 μ	50 μ	50 μ
Area examined	7·25 cm.^{2}	1·0	4·0	4·4
Volume examined	0·145 cm.^{3}	0·02	0·02	0·022
Small stars	160	25(22)	37(22)	43(24)
Large stars	15	2(2)	4(2)	2(2)
Total stars	175	27(24)	41(24)	45(26)
Stars with one associated single track	24	3	8	4
Stars with two associated single tracks	11	..	2	1
Stars with three associated single tracks	2	..	..	..
Total no. of single tracks	446	67(62)	76(52)	66(57)
Single tracks associated with large stars	1	..	2	..
Single tracks associated with small stars	51	3	10	6

In this table a track is classified as being near a star if the centre of the track lies within 150 μ of the centre of a star. The figures in brackets are the expected numbers, if the Bangalore flight plates are taken as standard. They are calculated on the basis of the ratio of the respective volumes of emulsion examined. For the tracks the two boundary layers, of thickness 5 μ, at the upper and lower surfaces of the emulsion, are excluded, since if the centre of a track lies in one of these layers the chance is less than $\frac{1}{2}$ that both its ends will lie in the emulsion, assuming a mean length of 20 μ for the track (see below). In the Bangalore flight plates the frequency of tracks near stars is 9·7 times the chance expectation. The expected number of tracks near stars for the Madras plates has been calculated on the assumption that this ratio is maintained.

The table makes clear that the concentration of tracks near stars is greatly in excess of any chance distribution. In the Bangalore flight plates, if the 446 tracks were distributed at random throughout the volume examined, only five would be expected to fall within 150 μ of a star. The chance of finding two tracks within 150 μ of the same star would be 0·16, and the discovery of even one case would be very improbable. In the Bangalore flight plates the results show 52 tracks near stars and 11 stars with two associated tracks. We conclude that there is a real physical association between the tracks and the stars.

A second feature of the results in Table I is that there is no difference exceeding the statistical uncertainties, in either set of experiments, between the flight plates and the control plates. Whatever is responsible for the production of the stars and single tracks must therefore have an appreciable intensity at ground level. The period spent at high altitudes is of the order of 0·4% of the total life of the plates for the Bangalore flights, and 0·08% for the Madras flights. Unless the intensity of production is greater at high altitudes by a factor of at least 100 one would hardly expect significant differences in the observed numbers between the flight plates and the control plates. This question can only be settled by examining plates which have been exposed at high altitudes for a longer fraction of their total life.

The total life of the Bangalore plates was approximately one month, and that of the Madras plates five months, between manufacture and development. One would expect, therefore, that the numbers of stars and single tracks in the Madras plates, for the same volumes of emulsion, would be larger than the corresponding numbers for the Bangalore plates in the ratio 5: 1. Comparison with the figures in brackets shows that the ratio is about 2: 1 for stars and about 1: 1 for single tracks. This can be explained qualitatively as the result of fading. Fading would produce a general reduction in the number of events observed, but it is to be expected that fading would be less pronounced for stars than for single tracks, as the stars frequently have heavily ionised tracks which would persist longer.

Of the 446 tracks in the Bangalore flight plates, 416 have ranges in the emulsion between $10\,\mu$ and $40\,\mu$. The distribution curve of these tracks is shown in Fig. 1, which shows a prominent maximum in the neighbourhood of $19\,\mu$. Fig. 2 shows a similar curve for the Madras flights, for which we have used not only the 76 tracks of Table I, but also 201 tracks measured in other areas. There are 265 tracks with ranges between $10\,\mu$ and $40\,\mu$. The maximum is in the neighbourhood of $20\,\mu$. The ranges are corrected for shrinkage, and are the true ranges in the unprocessed emulsion.

For all the tracks in Figs. 1 and 2 the distance p between the centre of the track and the centre of the nearest star has been measured. The tracks have then been divided into two groups: (i) those for which $p \leqslant 150\,\mu$, (ii) those for which $p > 150\,\mu$. The separate distribution curves are shown in Figs. 3 and 4 for the Bangalore and Madras plates respectively. It will be seen that there is now strong evidence of two different ranges. Fig. 5 is plotted from the Bangalore flight results for $p \leqslant 100\,\mu$ and $100\,\mu < p < 300\,\mu$, giving comparable numbers of tracks in the two histograms. The two ranges are clearly resolved.

It appears from these results that we are dealing with two distinct groups of single tracks: (i) those occurring near stars, which have a range of $25\,\mu$ in the Ilford emulsion and $23\,\mu$ in the Kodak emulsion; (ii) tracks not concentrated near stars, which have a range of 20 μ in the Ilford emulsion and 19 μ in the Kodak emulsion.

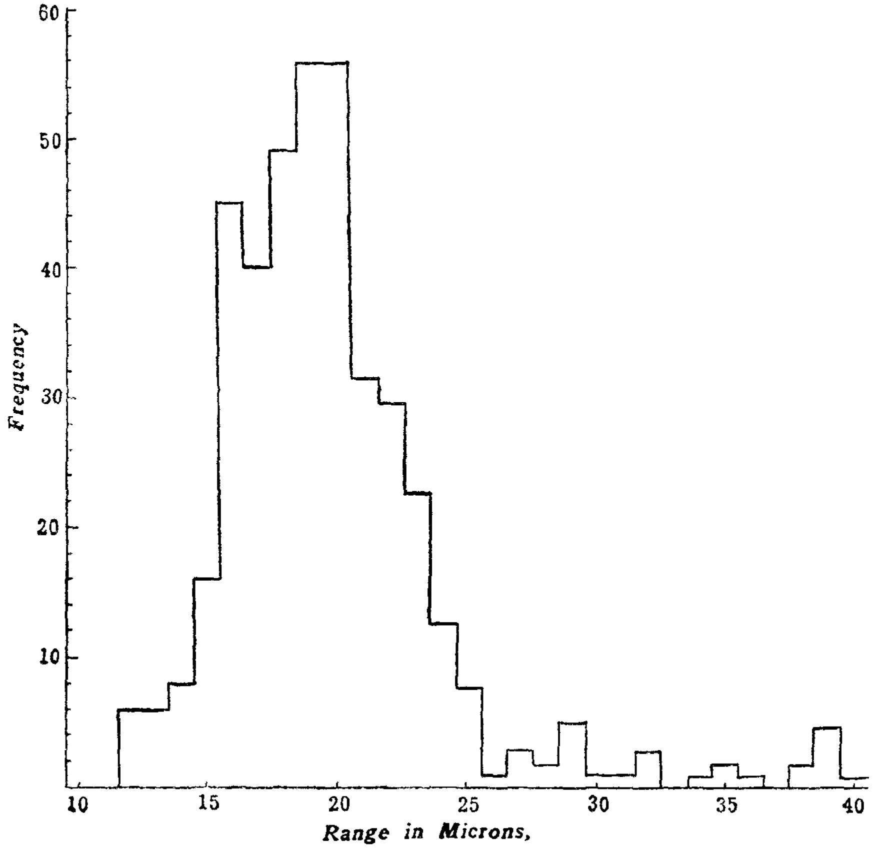


Fig. 1. Range—frequency histogram of all isolated tracks in the Bangalore flight plates.

To deduce the corresponding air ranges we require a knowledge of the stopping powers of the emulsions. The stopping power varies with the energy[1] and with the nature of the particle, and the values determined from the measured ranges of known α-particles are not necessarily exact. We choose as the most likely values a stopping power of 1650 for the Ilford emulsion and 1800 for the Kodak emulsion. The two ranges then become 3·3 cm. and 4·1 cm. for the Ilford emulsion, and 3·4 cm. and 4·1 cm. for the Kodak emulsion. As we have substantially more measurements for the Kodak emulsion we take the later values, 3·4 cm. and 4·1 cm., as the best ranges we can at present deduce for the two groups of particles. It is unlikely that the maximum error in these values will exceed 0·2 cm.

The question arises whether the single tracks could be due to radioactive contamination. The natural α-particle ranges in this region are: Th.X, 4·32; Ac.X, 4·29; Rn, 4·05; Ra.C, 4·0; RdTh, 4·0; Po, 3·84; Pa, 3·51; Ac, 3·46; Ra, 3·26; U.II, 3·21. Of these we may exclude RdTh and U.II, which would be accompanied respectively by Th (2·43) and U.I (2·65), and Po, of which the range fits neither of the measured groups. It would be very difficult to account for the presence of any of the other elements in sufficient amount. They would give, moreover, a population consisting chiefly of stars rather than single tracks, whereas the observations show that the single tracks are nearly three times as numerous as the stars. It has been supposed that radioactive atoms may migrate through the emulsion in the interval between disintegrations, so producing single tracks separated from the stars to which they belong. There is no evidence, however, that these movements can exceed a few microns, and if they occur,

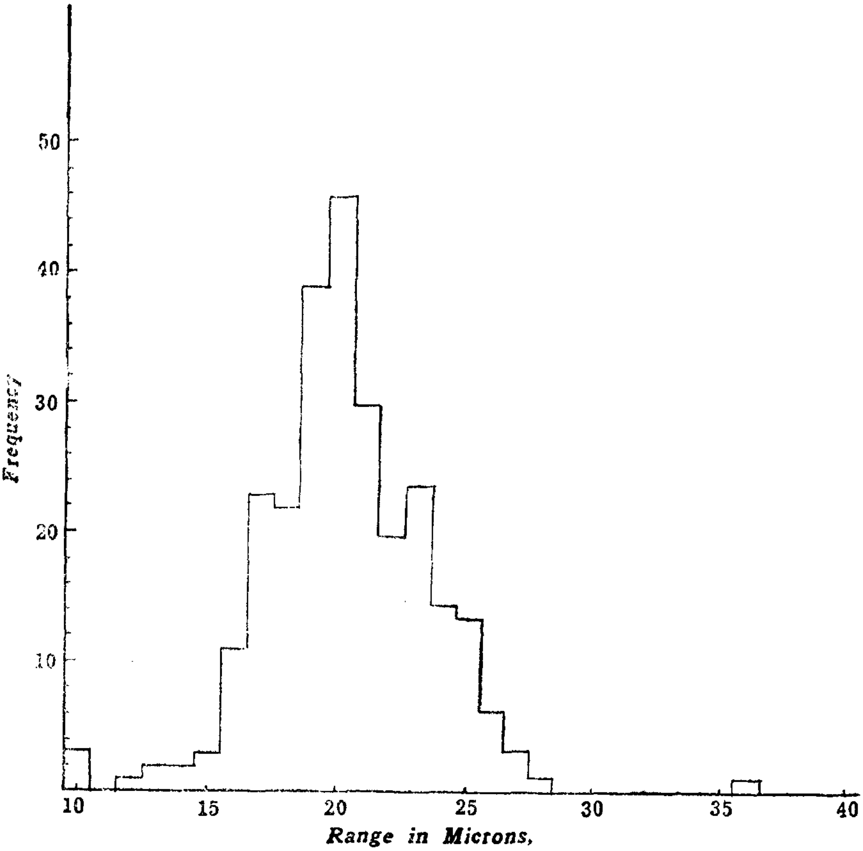


Fig. 2. Range—frequency histogram of all isolated tracks in the Madras flight plates.

most of the stars should show small displacements of individual tracks, which are not observed. The hypothesis also leaves unexplained the observed large number of isolated tracks not associated with stars. In some cases single tracks are found associated with large stars, which can certainly not be explained by radioactive contamination.

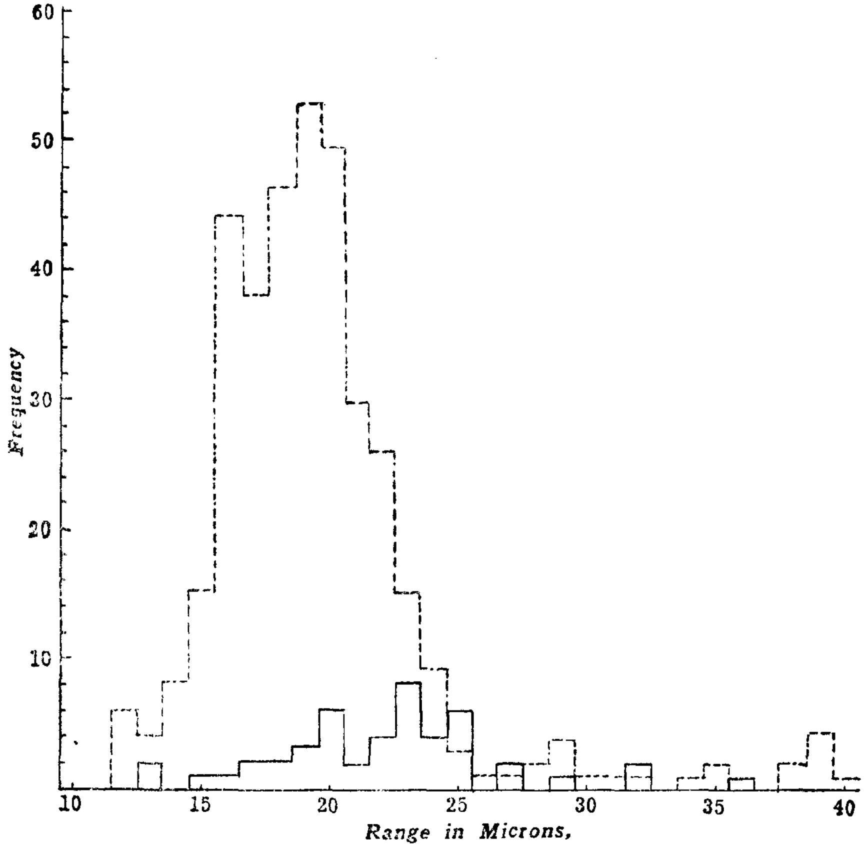


FIG. 3. Range—frequency histograms of isolated tracks in the Bangalore flight plates.
(*a*) Solid lines represent tracks found within 150 μ from stars.
(*b*) Dotted lines represent tracks found at distances > 150 μ from stars.

An alternative hypothesis is that the single tracks are produced by neutral particles emitted from the stars. Such a particle might (*a*) produce a track by a knock-on process, (*b*) initiate a nuclear disintegration, (*c*) spontaneously disintegrate in flight.

Considering first hypothesis (*a*), we can exclude the possibility that the track is formed by the knocked-on particle, since its energy would depend upon its direction, and the observed constancy of range would not occur, The observations show, moreover, that the orientation of the single tracks is approximately random, and bears no relation to the direction of the line joining the track and the star. One might suppose, however, that there is an exchange of charge in the interaction, so that the original neutral particle becomes a charged particle and is responsible for the observed track. If we also suppose that the neutral particle is emitted with constant energy, and that its mass is small compared with the particle with which it collides, its energy loss in the collision would be almost independent of the direction of scattering, which would explain the observed constancy of range. The cross-section, however, would have to be extremely large, of the order of 20,000 barns or more. Hypothesis (*a*) in this form appears very improbable.

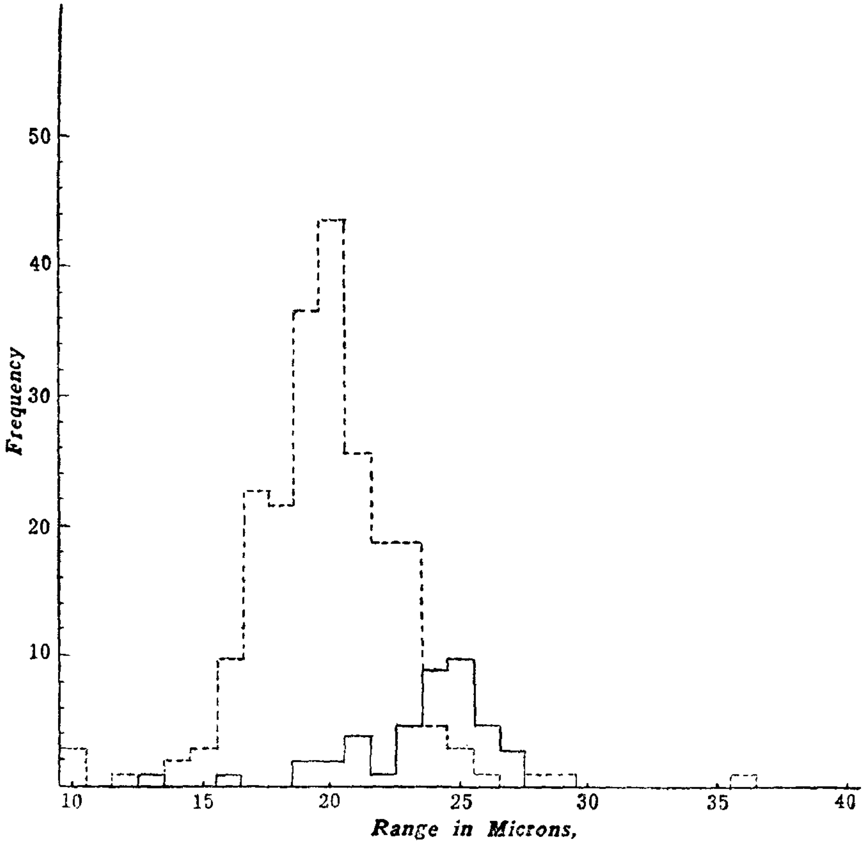


Fig. 4. Range—frequency histograms of isolated tracks in the Madras flight plates.
(*a*) Solid lines represent tracks found within 150 μ from stars.
(*b*) Dotted lines represent tracks found at distances > 150 μ from stars.

Hypothesis (*b*) cannot be definitely excluded, but to explain the longer-range group of tracks, most of which appear to lie within 150 μ of the associated star, the cross-section would again have to be large, of the order of 20,000 barns for the more abundant elements in the emulsion, and even larger for the others.

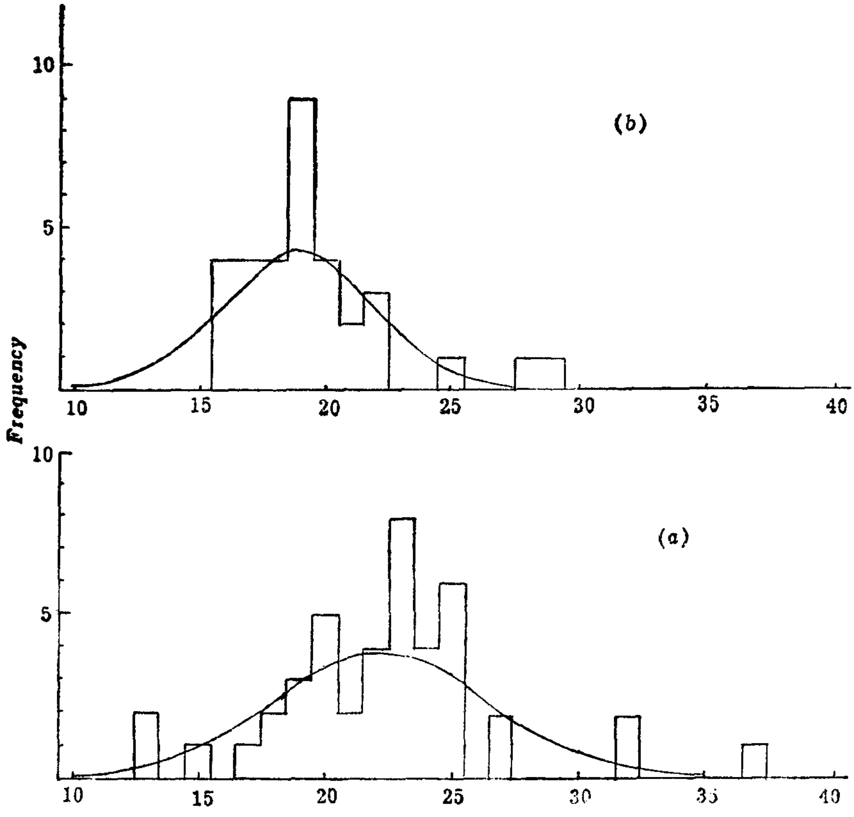
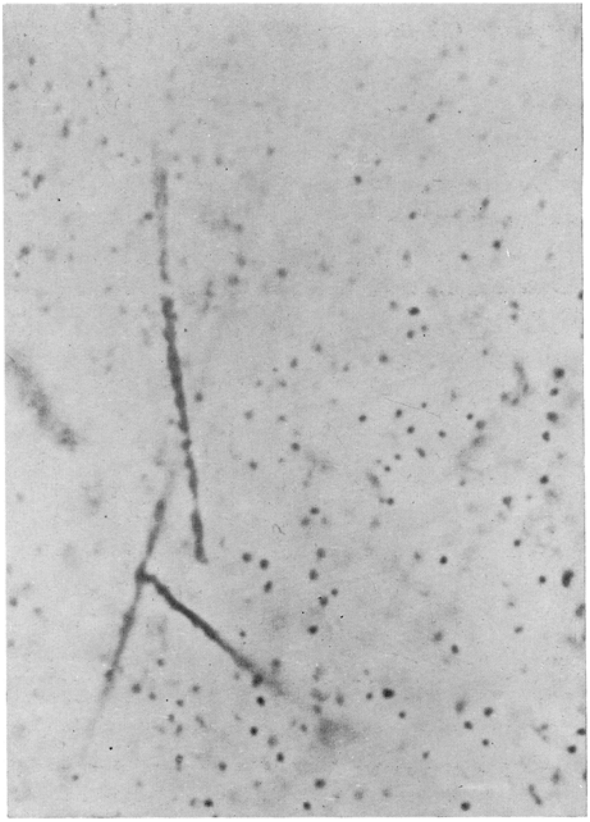


FIG. 5. Range—frequency histograms of isolated tracks in the Bangalore plates.
(*a*) For tracks found within 100 μ from stars.
(*b*) For tracks found between 100 μ and 300 μ from stars.
Normal distribution curves have been fitted for both the histograms.

Hypothesis (*c*) would involve a disintegration of the neutral particle into two charged particles, negative and positive, which would be projected in opposite directions and appear as a single track. If the momentum of the disintegrating particle were appreciable the two resulting tracks would not be collinear. A number of the tracks do indeed show a slight bend, varying between 1° and 10°, and if these represent cases where the resultant momentum is appreciable, the star from which the neutral particle emanates must lie on the convex side of the observed angle. There are 19 tracks having a distinct bend which lie near to stars, and in 14 cases the star lies on the convex side of the angle. It must be realised, however, that with such short tracks the measurements of angle are subject to much uncertainty. A slight apparent bend may be produced by distortion of the track, by irregularity in the grains, or by scattering. The fact that the two parts of the bent tracks do not show a constant ratio of length suggests that they do not represent the two opposite particles resulting from a disintegration. If hypothesis (*c*) is correct we would conclude that the neutral particles come out with very low energy, and that the observed bends are largely due to scattering.

The grain density of the single tracks is very variable, for which differential fading is doubtless responsible. It is therefore not possible to deduce the nature of the particle producing the track, but an ionising power comparable to that of a slow proton would be consistent with the present observations. On hypothesis (*c*) if one of the resultant particles were an electron, or other lightly ionising particle, it would have been recorded in the N.T.4 emulsion, which shows the minimum ionisation tracks reported by other workers.[2]

Another possible hypothesis (*d*) is that the star and the associated tracks are produced independently by particles belonging to the same cosmic-ray event initiated in neighbouring matter. In the ' broom ' type of shower[3] several closely associated particles move forward in a narrow-angle cone, and neutral particles may be included in such a shower. If the observations are to be explained in this way it would be necessary to assume two kinds of neutral particle, one responsible for the star and the other for the associated track. Let n be the number of track-producing particles in the shower, each having a probability p of producing a track in passing through the emulsion. The probabilities P_1, P_2, P_3.... of obtaining 1, 2, 3.... associated tracks in the same event depend only upon n and p. The ratios P_2/P_1 and P_3/P_1 are obtained from the data in Table I, from which we may calculate n and p. The observed numbers are consistent with a value of n about 3 or 4. The large number of stars without an associated track would then indicate that star-producing particles are not necessarily accompanied by track-producing showers. If we assume that the single tracks are produced by neutral particles it appears necessary, on any hypothesis, to postulate two different types of particle, or one type existing in two alternative states, to account for the experimental fact that two distinct ranges are found.



Photomicrograph of a typical three pronged star with an associated single track.

It is evident that more observational data are needed before the difficulties can be resolved, but in the light of the present results hypothesis (*c*) appears the most plausible. One would then interpret the shorter-range group of tracks as arising from the disintegration of a neutral particle of somewhat larger lifetime and correspondingly smaller disintegration energy, emanating from stars formed chiefly in the glass and in neighbouring matter. The longer-range group would arise from the disintegration of a particle of shorter life and greater disintegration energy, emanating from the stars with which the tracks are associated. It would be necessary to postulate extremely short lifetimes, possibly of the order of 10^{-9} sec.

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SUMMARY

Photographic plates exposed at high altitudes show a population of stars and isolated single tracks. Statistics are given covering 288 stars and 655 isolated tracks found in an area of 17 sq. cm. Some tracks are closely associated with the stars, and these have a mean range of 4·1 cm. air. The remainder, which show no association with stars, have a mean range of 3·4 cm. air. Some stars have more than one associated single track. Alternative explanations are discussed. The most probable hypothesis appears to be that the single tracks are due to the spontaneous disintegration of unstable neutral particles emitted from the stars.

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