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HIGH ENERGY ALPHA PARTICLES ASSOCIATED WITH FISSION

by

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HIGH ENERGY ALPHA PARTICLES ASSOCIATED WITH FISSION

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In this work the photographic emulsion technique has been applied to the study of the long range particles given off during neutron irradiation of uranium.

Alvarez first observed these particles with an ion chamber and linear amplifier. Segre, et al (LA-87) studied these particles with an ion chamber which gave coincidences between these particles and fission. They found them to be coincident with fission within the time constant of their circuit ($\sim 5\mu$ sec). They were also able to identify these particles as alpha particles from the density of ionization near the end of the tracks. Hughes has observed a number of these alpha particles in the cloud chamber, but his setup did not permit him to observe the associated fission track.

The cloud chamber or photographic emulsion technique permits information to be obtained about the alpha particles and their association with the fission process that cannot be got by the ion chamber method.

The photographic emulsion technique has been used in this case because it lends itself very well to a study of rare events of this type.

EXPOSURE OF PLATES

Eastman alpha particle plates with an emulsion thickness of about 50μ were used. It was desirable to obtain as large a number of fission events in the emulsion as possible without too high a background. It was found that the plates could be soaked in a saturated water solution of uranyl acetate without damaging the emulsion.

Plates soaked in this solution for 30 minutes were rapidly dried and then exposed near the edge of the reflector of the Clinton Pile for 1 or 2 sec. This gave of the order of 10^6 fission tracks on a 3 inch x 1 inch plate. Control plates (a) irradiated but unsoaked and (b) soaked but not irradiated were made as a check on natural alpha particle tracks and recoil protons from the small per cent of fast neutrons from this place in the pile. A single good plate which can be made in a few hours after the conditions of exposure have been determined furnishes material for a long and tedious examination under the microscope.

TRACK DATA

A plate area of about 10 cm^2 has been searched for long range alphas. In all cases to date in which both ends of the alpha track are observed to lie in the emulsion, it has been found that the alpha particle originates near the center of a fission track. So far twenty such tracks have been observed and measured. The data on these tracks are given in Table 1. The lengths and number of grains are listed for each fission particle track and for the alpha particles. The true angle between one fission fragment and the alpha track is given as θ. This angle was determined from the horizontal projection angle and the depths of the track ends in the emulsion. The deviation of the fission track from a straight line is listed as Δ. Natural curvatures in the tracks make it impossible to expect any accuracy in these

Table 1.

No.	Fission fragment tracks				Alpha tracks		Angle of α with fission	Deviation of fission tracks from 180°	Range of α in cm air*	Energy of α mev
	Length microns	No. of grains	Length microns	No. of grains	Length microns	No. of grains	$\theta°$	$\Delta°$		
1	10.0	11	10.2	14	282	138	130	-	39.4	22.1
2	17.0	10	16.0	10	154	66	72	-	21.6	15.2
3	14.5	16	17.5	8	160	82	80	-	22.4	15.6
4	13.8	10	12.8	8	284	140	51	-	39.7	22.2
5	13.5	9	12.7	7	154	65	75	12	21.6	15.2
6	8.5	10	9.5	9	208	97	17	-	29.0	18.2
7	9.9	11	9.45	14	207	94	84	10	28.9	18.1
8	10.35	12	14.2	14	244	129	62	4	34.2	20.2
9	9.5	6	11.5	11	64.5	27	88	2	9.0	9.2
10	14.5	9	10.2	8	97	48	72	6	13.7	11.6
11	12.2	8	11.5	8	161	94	83	2	22.4	15.6
12	11.5	9	10.0	9	108	66	72	0	15.1	12.2
13	10.6	9	13.1	11	160	71	57	23	22.4	15.6
14	11.1	9	7.8	8	105	49	73	−2	14.7	12.0
15	15.8	10	14.0	10	251	115	82	0	35.2	20.3
16	9.3	6	11.3	8	256	122	90	8	35.8	20.8
17	13.9	10	10.5	11	186	97	87	2.5	26.0	17.0
18	14.3	11	14.0	9	111	60	86	5	15.6	12.6
19	10.7	9	10.7	9	171	74	90	8	23.9	16.1
20	9.4	10	10.5	5	151	80	89	0	21.2	15.0

*The stopping power of the emulsion is taken as 1400 times that of air.

values. Most of the angles are, however, positive, as is to be expected for conservation of momentum.

In order to get a good microphotograph of a track, it should lie nearly in a plane perpendicular to the axis of the microscope. So far no track has fulfilled this condition for both the fission and alpha particle. A few cases have, however, been photographed and are shown in Figures 1, 2, and 3. All these photographs have been made by piecing together sections of the track for which the grains were in approximate focus at one setting of the microscope. In Figure 3 it can be seen that the track has been retouched in a few places where the grains were not in sharp focus.

In Figure 2 a short proton track has been included for comparison of grain spacing with the alpha track. This point is discussed in the next paragraph.

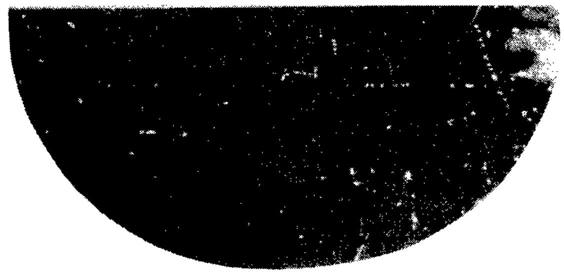

Figure 1. Long alpha track associated with fission. 620 Diameters

Figure 2. Long alpha track associated with fission (upper picture) as compared with a recoil proton track (lower picture). The difference between the two tracks can be seen by comparing their average grain spacings. The pictures are so placed that the ends of the tracks fall at the same distance from the left side of the page. 380 diameters.

Figure 3. Long range alpha associated with fission. 810 diameters.

EVIDENCE THAT PARTICLES ARE ALPHAS

Alpha particle tracks can be distinguished from proton tracks by the relative grain spacings along the tracks. To check this, a plate was exposed to fast neutrons from the cyclotron and the grain spacings for long recoil proton tracks were measured. In Table 2 comparison is made of the grain spacing for two (α_1 and α_2) of our so-called long range alpha tracks with the average spacing for 6 long proton tracks.

Table 2.

Tracks	Grains per 20 microns as a function of distance from end of track in microns						
	0–20	20–40	40–60	60–80	80–100	100–150	150–200
$\alpha 1$	14	14	13	13	11	10.2	8.8
$\alpha 2$	10	14	13	11	13	8.4	8.8
Average of 6 proton tracks	10	9	6	6	5.5	3.4	3.4

Figure 4 shows the data of Table 2 in graphical form. It is obvious that alpha particles and protons can be readily distinguished in the emulsions.

EVIDENCE FOR ALPHA PARTICLES BEING EMITTED IN FISSION PROCESS

The fact that the alpha particles originate near the center of the fission track does not in itself show that these alphas are liberated in the fission act, they may be ejected from one of the fission fragments left in a highly excited state.

The time scale given by the velocity and range of the fission particles is very short in a photographic emulsion. The time for a fission particle to travel 10 microns in the film is in the neighborhood of 10^{-12} sec. The alpha must then be coincident with fission within something less than this time. For alpha particles of the high energy encountered here, however, even this short a time is long compared to the average life time before emission of the alpha particle and hence this gives no information regarding the nature of the process.

If the alpha particles were emitted from the fission fragments after fission had occurred, one should expect a random angular distribution of the alphas with respect to the fission tracks. This would mean an angular distribution function $N(\alpha)d\alpha = \sin \alpha d\alpha$ in the center of gravity system from which the angular distribution function in the laboratory system can be calculated for a given energy and mass of the alphas and the fission fragments. This was done by an approximate method for the case $E_f/E_\alpha = 6$ and $m_f/m_\alpha = 24$ giving $V_\alpha = \lambda V_f$, which roughly satisfies the average conditions. It is found on this basis that in the laboratory system there is a preponderance of alphas emitted near 45° with its fission track, but when the emission for the two fission fragments is averaged, the distribution function is not very different from that in the center of gravity system, being slightly higher than the sine function at small angles.

If, instead of being emitted by a fission fragment, the alpha particle is more or less pinched off between the two heavier fragments in the fission act, then it is to be expected that the angular distribution of the alphas will favor the direction normal to the fission track. This is readily seen when one considers the forces on the alpha particle located in the region between two positively charged particles. The path which the alpha particle will travel will be determined by the magnitude and direction of its initial velocity and on the magnitude of the charges carried by the fission fragments. If the

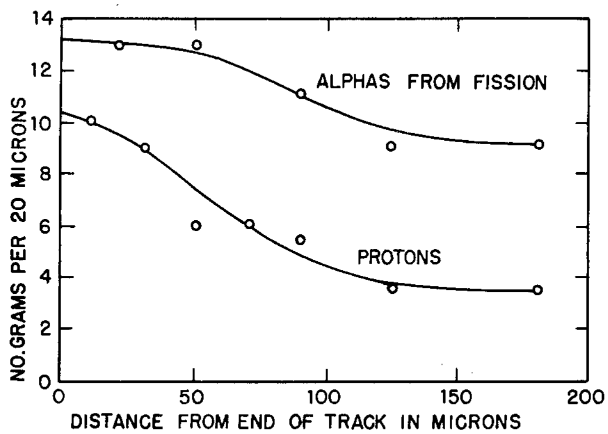

Figure 4. Grain spacing along track for alphas and protons.

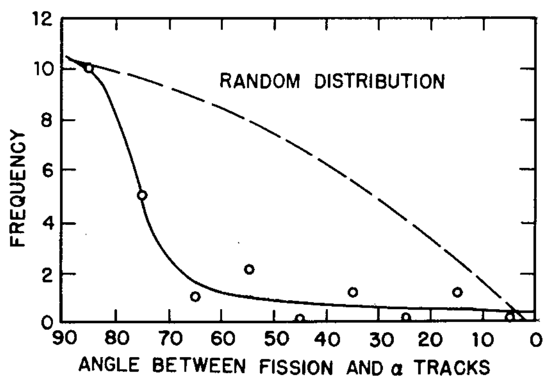

Figure 5. Distribution of angles between alphas and fission tracks.

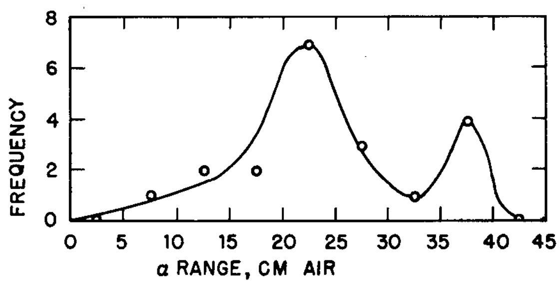

Figure 6. Range distribution of alphas from fission.

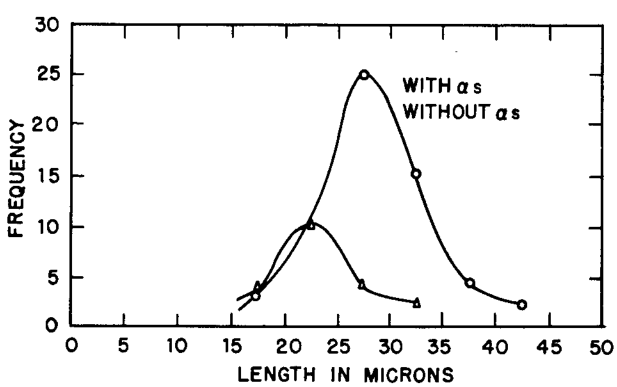

Figure 7. Distribution of total fission track length for normal fission and fissions with associated alphas.

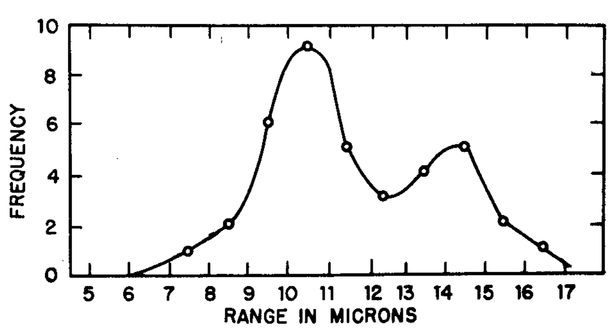

Figure 8. Range distribution of individual fission fragments for fissions with associated alphas.

initial velocity is small, the alpha will move down the potential valley of the two charged particles, in which case the alpha will make a large angle with the fission track. With a large initial velocity, however, any angle is possible.

The angular distribution of the twenty particles given in Table 1 is plotted as the solid line and points of Figure 5. The dashed line is for random distribution. The observed distribution is sufficiently different from the random case to indicate quite definitely that many of the alphas at least are ejected in the fission act. This might be taken as the first evidence of the existence of three particle fission, although this is certainly a very special case of such a process.

RANGE AND ENERGY OF ALPHA PARTICLES

We have not yet been able to make accurate stopping power determinations for the alpha particle plates which we have been using, but this has been done previously for these plates. From the literature it seems that the stopping power of the plates relative to air is about 1400. Using this value and Bethe's energy loss formula, the energy of the particles has been calculated. The range in air and the calculated energy are tabulated in the last two columns of Table 1. An energy distribution curve is plotted in Figure 6. No significance can, of course, be given to th shape of the curve since only 20 particles have been measured. The highest energy alphas (~22 Mev) which we find are higher than any of those reported so far by Alvarez, Segre, or Hughes, and are much higher than any alphas previously observed to accompany any natural process.

RANGE DISTRIBUTION OF FISSION FRAGMENTS

The distribution in length of the normal fission tracks (total track) is plotted in the upper curve of Figure 7. The range distribution for the fission tracks which are accompanied by alpha emission is plotted in the lower curve of the same figure. It is seen that the average range of the latter is about 20% less than for normal tracks. This is to be expected if the available energy is about the same in the two cases, and in one case the alpha takes off from 10% to 15% of the energy.

For the fission tracks listed in Table 1, a distribution in range can be plotted for individual fragments, since the alphas mark the point of origin. Such a distribution curve is shown in Figure 8. With only 40 tracks, the accuracy of the curve is necessarily low, but it is felt that the two groups are within the accuracy of the data to resolve. Two groups might be expected from the two energy groups associated with the light and heavy fragments as shown by Jentsche* and Flammersfeld, Jensen and Gentner.†

It is hoped later to gather more data on this process both by the photographic emulsion and by the cloud chamber method.

We appreciate the cooperation of the members of the Clinton Laboratory in permitting us to expose our plates in the Clinton pile.

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*Jentsche, W., Zeit.f.Phys. 120:165 (1943).

†Flammersfeld, A., P. Jensen, and W. Gentner, Zeit.f.Phys. 120: March (1943).

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