TRIPLE DISINTEGRATIONS OF URANIUM NUCLEI

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A study was made of the disintegration of uranium by 460-Mev and 660-Mev protons into three multiply-charged particles: two particles of the heavy fragment type and the third with considerably smaller mass and charge. The yield for given proton energies, the angular distribution of the light multiply-charged particles (front-to-back ratio), and their distribution in charge and energy were determined for such triple disintegrations. A mechanism is proposed for the triple disintegrations and the fragmentation cross section of uranium is estimated on this basis.

1. INTRODUCTION

In scanning plates with uranium-loaded emulsion which have been irradiated with high-energy protons, one observes disintegrations with emission of three multiply charged particles (cf. the figure in the insert). Such events occur approximately once in 200 or 220 cases of normal binary fission for incident proton energies of 660 Mev, and once in 400 cases for protons of 460 Mev. Up to now, 43 such disintegrations have been found and studied.

These disintegrations can be divided into two types. Type I consists of those disintegrations in which the ranges of all three multiply-charged particles are approximately equal. The equality of the ranges implies approximate equality of the masses.

The disintegrations of type II are those in which one of the three multiply-charged particles has considerably greater range in the emulsion and consequently much lower mass than the other two. The yield of triple disintegrations of type II is greater than that for type I by a factor of 5 or 6. It should be mentioned that in the majority of disintegrations of type II, in addition to the three multiply-charged particles one also observes tracks of protons and α particles, with an average of 1.6 charged particles per disintegration, whereas none of the disintegrations of type I are accompanied by emission of charged particles.

The present paper describes the results of a study of disintegrations of type II. The reason for this restriction is that up to the present time a satisfactory method for determining the nature of particles in nuclear emulsions has been developed for charge values up to $Z = 11$,[1] whereas there is no reliable method for identifying multiply-charged particles from their tracks in emulsion for larger values of the charge. Thus all the subsequent statements will refer to disintegrations of type II.

2. EXPERIMENTAL RESULTS

The main results are the following.

(a) The yield of triple disintegrations increases with incident proton energy; for example it doubles when the proton energy is changed from 460 to 660 Mev.

(b) The light multiply-charged particle in the triple disintegrations is emitted preferentially in the forward direction relative to the incident proton beam. The front-to-back ratio is ≈ 5.

(c) We give below the charge distribution of the light multiply charged particles. The charge was determined by the photometering method[1] in 22 cases:

Charge of particle:	4	5	6	7	8	9	10	11
Number of particles:	8	5	1	4	0	2	1	1

From these data the average charge is ~ 6.

(d) The table gives the energy of the light multiply-charged particles as determined from the range-energy curve[2,3] and the energy of the Coulomb interaction* between the light multiply charged particle and the residual nucleus. The charge of the residual nucleus was taken to be $Z = Z_t - (Z_l + \Delta Z)$, where Z_t is the charge of the uranium nucleus, Z_l is the charge of the light multiply-charged particle, and ΔZ is the change of charge

*In computing the Coulomb interaction we set $r_0 = 1.45 \times 10^{-13}$ cm.

Z	4	5	6	7	9	10	11
E_{exp}, Mev	17 30 28 22 48 32 25 36	21 78 57 25 34	48	52 65 78 54	80 40	55	70
E_{Coul}, Mev	42	51	60	71	85	92	102

associated with emission of protons and α particles in the particular disintegration.

3. DISCUSSION OF EXPERIMENTAL RESULTS

The data on dependence of yield on incident proton energy, angular distribution of the light-multiply charged particles, and their charge distribution are not in contradiction with the assumption that these disintegrations occur as the result of the superposition of two processes: emission of a light multiply-charged particle (a fragment) by the nucleus, and subsequent normal fission of the residual nucleus. Assuming this mechanism for the production of triple disintegrations, we can evaluate the cross section for fragmentation of uranium or the ratio of the fragmentation cross section to the cross section for inelastic processes, and compare the result with the similar ratio obtained for a nucleus in the middle of the periodic table, such as silver, since the fragmentation cross section has been determined for this element.[4] We have:

$$\frac{\sigma_{fr}(U)}{\sigma_{in}(U)} = \frac{N_{fr}(U)}{N_{int}} = \left(N_T \frac{\sigma_{in}(86)}{\sigma_f(86)}\right) \Big/ \left(N_f \frac{\sigma_{in}(U)}{\sigma_f(U)}\right).$$

Here N_T is the number of disintegrations of type II (30 for $E_p = 660$ Mev) observed for N_f binary fissions (= 6300); $\sigma_f(U)$ is the uranium fission cross section[5] (= 1.1 barns); $\sigma_{in}(U)$ is the cross section for inelastic interaction of uranium[6] (= 0.9 σ_{geom} or 2.2 barns); $\sigma_f(86)$ is the fission cross section of the residual nucleus. This last cross section was taken to be 0.4 barn in the computation; this value was based on the assumption that in the interval from bismuth (for which [7]$\sigma_f(Bi) \approx 0.2$ barn) to uranium the fission cross section changes proportionally to the change in Z. On substituting these values, we get:

$$(\sigma_{fr}/\sigma_{in})_U \approx 0.01 = (\sigma_{fr}/\sigma_{in})_{Ag}$$

and consequently $\sigma_{fr}(U) \approx 22$ millibarns (for incident proton energy $E_p = 660$ Mev).

The result obtained on the basis of our assumptions shows that the fragmentation cross section increases proportionally to the geometric cross section. This value for the fragmentation cross section of uranium (22 millibarns) was obtained under the assumption that the emission of the fragment from the target nucleus does not affect the probability of fission of the residual nucleus. If, however, the preceding fragmentation changes (increases or decreases) the probability of fission of the residual nucleus, we obtain a correspondingly increased or lowered value for the fragmentation cross section of uranium.

However, not all of the experimental data can be made understandable from the point of view of our assumption of superposition of the two processes — fragmentation and subsequent fission of the residual nucleus. Comparing the values of the experimentally observed energy and the Coulomb interaction energy given in the table, we see that in most cases $E_{exp} < E_{Coul}$, whereas for fragmentation of silver nuclei[1] the values of E_{exp} cluster around the values of the Coulomb interaction energy, and $E_{exp} \gg E_{Coul}$ in several cases. As mentioned previously, we computed the Coulomb energy for a spherical nucleus, assuming $r_0 = 1.45 \times 10^{-13}$ cm. However, if we compute E_{Coul} for a deformed nucleus, assuming for example $\Delta R/R = 0.2$, the values of E_{Coul} are decreased by approximately 10 Mev, which brings many of the values of E_{Coul} close to E_{exp}. But if in the

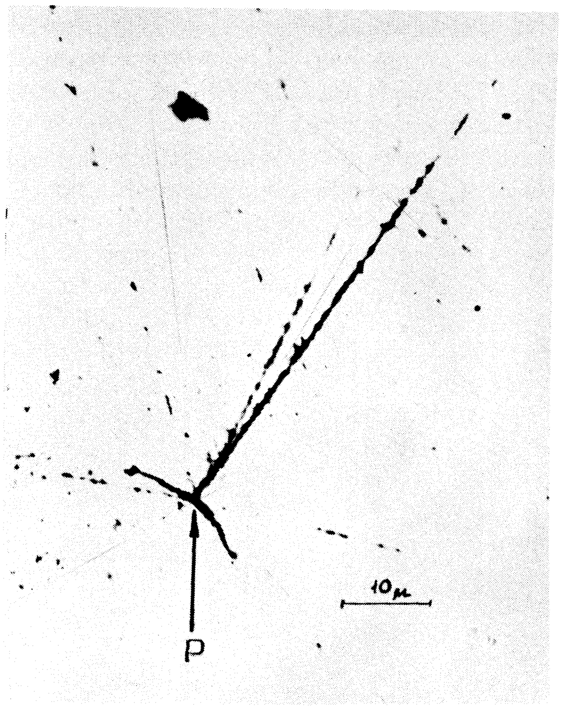

FIG. 1

majority of cases E_{exp} is actually less than E_{Coul} computed on the assumption of interaction of two charges (even taking account of nuclear deformation), this may indicate that there is simultaneity in the disintegration of uranium into three particles. Such events can be treated as triple fissions, but it is then not clear why the light multiply charged particle is emitted preferentially into the forward hemisphere.

For a more detailed study of the phenomenon of fragmentation of uranium nuclei, it would be interesting to study this phenomenon in pure form, i.e., not only to study disintegrations with three multiply charged particles, two of which may be assigned as fission products, but also to study disintegrations with one fragment. However, such a study is not possible if the emulsion is loaded with uranium by soaking the plate in a water solution of some uranium compound. With such a loading procedure, it is not possible to separate fragment-containing stars from disintegration of uranium from similar stars from disintegration of silver nuclei. Besides, there will be more fragment-containing stars from disintegration of silver nuclei because the number of Ag nuclei in the emulsion is approximately two orders of magnitude greater than the number of uranium nuclei loaded into the emulsion.

One solution to this problem is to introduce the element in which fragmentation is to be studied in the form of grains of dimension 3 to 6 μ into the middle layer of a three-layer plate.[8] However such a method requires a very long time of searching for disintegrations, in view of the low probability for producing a disintegration containing a fragment in such grains.

In our laboratory, the fragmentation of bismuth nuclei is being studied by the method of introducing elements into the emulsion in the form of grains. The results will be published later.

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