for distinguishing 1-chloro-1-propene from its isomers. The direct dissociation into an ion of mass 41 is by far the most probable result of electron collision, and the delayed dissociation a comparatively rare event. However, the relative peak height is not a direct measure of the abundance of metastable ions but depends in a complicated manner on the geometry of the instrument, and other factors.

It is hoped that this research will be continued with larger samples of higher purity.

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## Disintegration by Consecutive Orbital Electron Captures ${}_{56}\mathrm{Ba}^{131}\rightarrow{}_{55}\mathrm{Cs}^{131}\rightarrow{}_{54}\mathrm{Xe}^{131}$

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February 23, 1947

THE radiations emitted by two radioactive species in consecutive electron capture disintegrations have been studied. The mass number of the radioactive species is assumed to be 131 since ${}_{56}\mathrm{Ba}^{131}$ of half-life 11.7±0.3 days was obtained by $(n,\gamma)$ reaction of barium[1] with strong intensity of radiation after activation in a pile and by $(d,p)$ reaction with weak intensity of radiation after several hours bombardment in a cyclotron. The ${}_{55}\mathrm{Cs}^{131}$ formed by chain reaction was separated from barium, and the latter was chemically freed from other radioactive species. Sufficient time was allowed for disintegration of known short periods in barium.

Three gamma-rays of energies 220±10 kev, 500±15 kev, and 1.7±0.1 Mev were found to be present in barium. The most intense radiation was associated with the 500-kev gamma-rays while those of the 1.7-Mev gamma-rays were weak. Since the sources of $\mathrm{Ba}^{131}$ used for determination of energy of 1.7-Mev gamma-rays were of the order of 10 mc, the secondary radiations produced by absorbers were filtered off. Half-lives of barium measured for the three gamma-rays separately showed that the 220- and 500-kev gamma-rays belong to the 11.7-day barium. No information so far has been obtained that the 1.7-Mev gamma-rays do not correspond to the same period. Evidence of x-rays emitted by the barium fraction was obtained, but the x-rays were masked by the intense gamma-radiation especially by the 220-kev gamma-rays.

By cloud-chamber observations the particles emitted by the barium fraction were identified as electrons. For energies of more than 100 kev no positrons could be found. The electron spectrum of $\mathrm{Ba}^{131}$ and the full account of cloud-chamber observations will be published later.

By absorption measurements electrons of energy less than 500 kev were established. In addition, the shape of the absorption curve showed that electrons of less than 200 kev were very abundant.

The cesium fractions separated from activated barium immediately after activation and after 20-days accumulation were purified. The ${}_{55}\mathrm{Cs}^{131}$ decays with a period of 10±0.3 days, emitting highly converted gamma-rays of 145±10 kev energy. Conversion was calculated to be about 97 percent. In addition, x-rays of 0.412A were found to be present. Very intense radiation of electrons with energy of 112 kev were observed in ${}_{55}\mathrm{Cs}^{131}$ and identified as conversion electrons of 145-kev gamma-rays.

Thus, the transition, after orbital electron capture in mass number 131, from even to odd $Z$, considerably exceeds in gamma-energy emitted, the transition from odd to even $Z$.

It is a pleasure to express our appreciation to the Clinton Laboratories and its Isotopes Branch, Research Division, for activation of barium. The grant given by the Ohio State University Development Fund for construction of research instruments is gratefully acknowledged by the authors.

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[1] Manhattan Project Announcement, Science **103**, 697 (1946).

## On the New Fission Processes of Uranium Nuclei

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February 13, 1947

THE phenomenon of uranium fission has been known since 1939. It consists in the splitting of the uranium nucleus into two lighter nuclei, excited either by capture of a neutron, or by bombardment of charged particles or photons. The maximum energy liberated in this phenomenon is about 200 Mev, 150–160 Mev of which is used to project the two resulting nuclei in opposite directions, and the rest for the internal excitation of the fission fragments and the energy carried by the neutrons emitted during the fission. This well-known fission process is also called binary fission.

The possibility of fission into three charged nuclei has been pointed out by theoretical physicists,[1] predicting a liberation of maximum energy of 210–220 Mev, even 10–20 Mev higher than that of binary fission. But until now, definite experimental proof has not been published.

In order to search for the existence of fission into more than two charged fragments, experiments have been made with the *Ilford Nuclear Research* photographic emulsion, manufactured under the direction of Dr. Powell of the University of Bristol.[2] The plate was soaked in a 10 percent solution of uranyl nitrate, dried, and bombarded by slow neutrons produced near the Be target of the cyclotron of the Collège de France. With a suitable technique of development, the plate shows numerous thick fission tracks clearly distinguished from thin, natural $\alpha$-ray tracks. The major part of the fission tracks are straight lines, representing two nuclei projected in opposite directions, no determination of the origin of the fission fragments being possible. Occasionally, near the ends of the track, there are collisions between the fission fragments and the nuclei contained in the emulsion (branches and bendings).[3]

(*A*) *Ternary fission.* Certain fission tracks show a peculiar aspect: three tracks originate from a common point, usually two heavy tracks and one long lighter track (Figs.

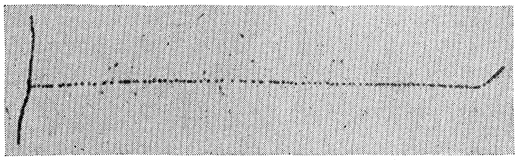

FIG. 1. Ternary fission: third fragment—mass≈9, range = 17 cm air equivalent.

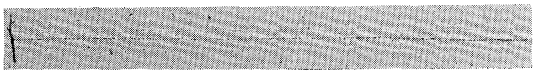

FIG. 2. Ternary fission: third fragment—mass≈6, range = 44 cm air equivalent. The two branches on one of the heavy fragments are caused by nuclear collisions.

1 and 2). Precise analysis, based on the conservation of momentum, shows that it is impossible to describe all of them as branches caused by a collision of the fission fragment at the beginning of its range, with a known nucleus contained in the emulsion (such as H, C, N, O, Br, and Ag). It seems more plausible to conclude that these are fissions of uranium into three charged fragments (ternary fission).

Taking account of the measured angles and ranges, and of the velocity-range relation of heavy ions,[4] and requiring conservation of momentum, we can determine the mass and energy of each fragment. The distribution of masses of the three fragments is shown in Fig. 3: the two heavy fragments have average masses of 99 and 131, respectively, the third fragment seems to have two probable values, one about 5 or 6, the other about 9.[5] The average total kinetic energy of ternary fission is 165 Mev, slightly higher than that of binary fission. If the total internal excitation energy is about the same for binary and ternary fission fragments, the agreement between the observed kinetic energy and the theoretical value may be regarded as satisfactory.

The ratio of ternary fission to binary fission is 0.003 ±0.001. This value may be regarded as the lower limit, because certain cases with a heavier third fragment are discounted from the statistics owing to the possibility of attributing them to nuclear collisions.

(*B*) *Quaternary fission.* Besides those of ternary fissions, we have observed some cases which cannot be explained otherwise than by fission into four charged fragments (quaternary fission). One of these has already been described in detail (Fig. 4).[6] It seems interesting to indicate that the observed ternary fissions are almost all of the same type, i.e., two heavy, and one light; whereas the quaternary fissions may occur in various fashions: (1) two heavy, and two relatively light (Fig. 4), (2) three heavy, and one light (Fig. 5). If the total internal excitation energy is about the same for binary and quaternary fission fragments, the mean observed kinetic energy for the latter, about 110 Mev, is in good agreement with that estimated by Bohr and Wheeler.[1,5] The ratio of quaternary fission to binary fission is 0.0003±0.0002.

The detailed report of this work will be published shortly in *Journal de Physique et le Radium.*

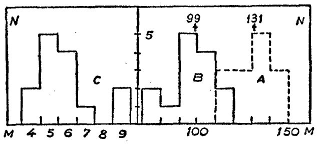

FIG. 3. Distribution of masses of ternary fission fragments.

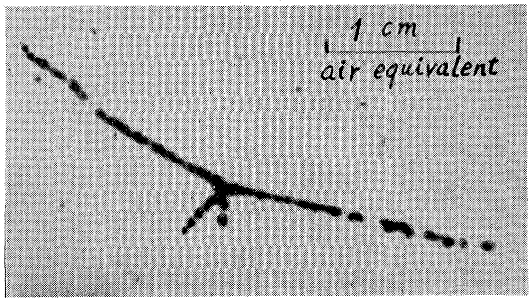

FIG. 4. Quaternary fission.

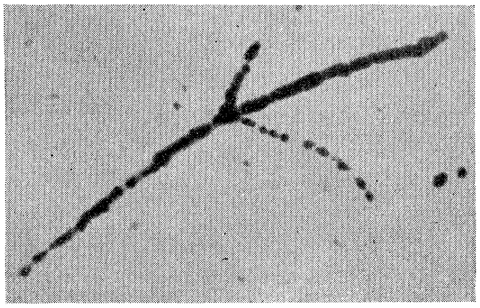

FIG. 5. Quaternary fission. (In same scale as Fig. 4.)

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[5] Tsien San-Tsiang, Ho Zah-Wei, R. Chastel, and L. Vigneron, Comptes rendus **224**, 272 (1947).

[6] Ho Zah-Wei, Tsien San-Tsiang, L. Vigneron, and R. Chastel, Comptes rendus **223**, 1119 (1946). In the table of this article, the data under the columns $M_3$ and $M_4$ should be exchanged. Similarly, those under $E_3$ and $E_4$ should also be exchanged.

## Microwave Absorption Frequencies of $N^{14}H_3$ and $N^{15}H_3$

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February 19, 1947

FIFTY microwave absorption lines of $N^{14}H_3$ and $N^{15}H_3$ have been observed in the region between 19,000 and 26,000 mc/s.[1-5] We have now remeasured the frequencies of all of these lines with a precision of better than one part

FIG. 1. Ternary fission: third fragment—mass$\approx$9, range$=$17 cm air equivalent.

FIG. 2. Ternary fission: third fragment—mass≈6, range=44 cm air equivalent. The two branches on one of the heavy fragments are caused by nuclear collisions.

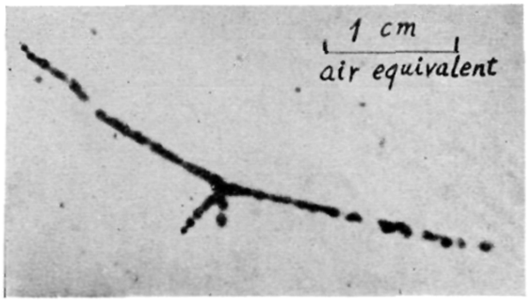

FIG. 4. Quaternary fission.

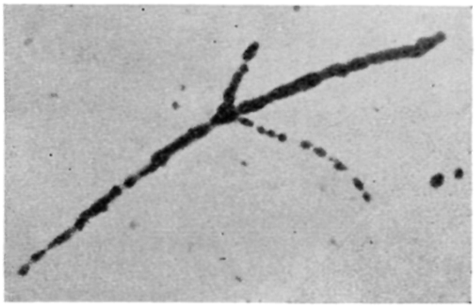

FIG. 5. Quaternary fission. (In same scale as Fig. 4.)