Radioactive Recoils from Uranium Activated by Neutrons

It has been shown by Hahn and Strassmann[1] and immediately afterward by others[2] in this laboratory and elsewhere that the uranium nucleus under neutrom bombardment sometimes splits into parts with about half the atomic number of uranium, and thus produces radioactive isotopes in the middle of the periodic table. The range of the ejected radioactive particles can be measured by observing the distribution of the activity with depth in a layer of matter placed next to the uranium during bombardment.[3]

An experiment of this kind was done by placing a stack of thin (0.57 mg/cm^2) Al foils in contact with a thin layer of UO_3 mounted on paper, and exposing to neutrons from the cyclotron. Then the activities of the separate foils were measured. The results are shown in Fig. 1 which gives

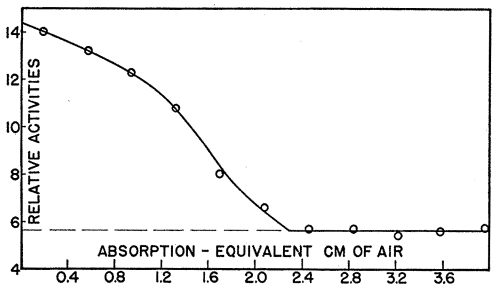

FIG. 1. Relative activities of aluminum foils plotted against the stopping power from the surface of the uranium sample in cm of air equivalent. The points are put at positions corresponding to the centers of the foils. The horizontal line represents the activity induced in the aluminum by the neutrons, and the curve shows the activity deposited by recoil from the uranium. The form of the curve near the end-point is not well determined by the data. The range may be estimated as 2.2±0.2 cm.

the relative activities at about two hours after the end of the bombardment. The horizontal line represents the "background" due to the activity induced in the Al itself. The last foil was omitted from the plot, since its activity is reduced about 30 percent by the recoil of the activated nuclei under the fast neutron impact, which drives some of them into the preceding foil. (The neutron source was to the right in the figure.) If the particles from the uranium had a homogeneous range, the distribution of activity would be rectangular. The observed shape can be explained either by supposing that there is a distribution of ranges, or by taking account of the finite size of the grains of UO_3. These grains have sizes ranging from about 40 microns down to 1/10 this or less. Since the mean diameter represents a stopping power of the order of the observed range, we can say that the results are not incompatible with an initially homogeneous range.

Another experiment was done to find out if there is any correlation between range and decay periods of the products. Cigarette papers of about one cm air equivalent stopping power were used instead of the Al foils. These were extracted with hydrochloric acid before use, and the UO_3 was mounted on filter paper, to avoid all mineral matter that would give extraneous activities. After bombardment, activity was found on the first three sheets of paper. The decay curve of the second sheet was followed for about 24 hours, and of the third for about 12 hours, and they were found to run parallel to that of the first sheet within the accuracy of the measurements. But the decay curve of the uranium sample (including the paper backing) showed quite striking differences from these. The uranium curve has a strong additional component of about 25 minutes half-life, which may be the substance identified by Hahn, Meitner and Strassmann[4] as a uranium isotope produced by resonance neutron capture, and also a long period (~2 day) which is strong compared with any activity of corresponding period in the recoil samples. (The intensity of activation is so great that the natural uranium activity can be neglected.) The ratio of the total activity on the paper sheets to the activity of the uranium sample is about $\frac{1}{6}$ at three hours after bombardment, when this ratio reaches its largest value. This means that at this time the total recoil activity from both sides of the UO_3 sample is about $\frac{2}{5}$ as great as the activity remaining in the uranium. Since a considerable part of the latter consists of the nonrecoiling activities mentioned above, it should be easy to make a complete separation of the recoils from the others by using a more finely divided uranium preparation. This work is being continued. By using thin inactive foils of organic material and a very thin layer of uranium, it should be possible to obtain a very accurate range curve of this method. The financial support of the Research Corporation is very much appreciated.

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[1] O. Hahn and F. Strassmann, Naturwiss. **27**, 11 (1939).
[2] These are too numerous to give individual references here.
[3] The same idea occurred to F. Joliot, who performed a similar experiment, and communicated the results in a letter to Professor E. O. Lawrence, received during the course of the above work. Joliot's result was reported at the January 30 meeting of the French Academy of Sciences. He found a recoil range of about 3 cm.
[4] L. Meitner, O. Hahn and F. Strassmann, Zeits. f. Physik **106**, 249 (1937).

Further Observations on the Splitting of Uranium and Thorium

Continuing a survey of the effects produced by bombarding uranium and thorium with neutrons we have measured the range of the energetic particles emitted. This was done by coating a movable plate with the substance to be investigated and observing the distance at which the particles could no longer be detected by an ionization chamber with a gauze front, connected to a pulse amplifier. The ranges found were 10.5±1 mm and 12.0±2 mm for the particles from uranium and thorium, respectively.

To test the possibility of the delayed emission of neutrons a boron-lined ionization chamber was placed a few centimeters from a lithium target used as a source of neutrons, both the chamber and the target being surrounded with paraffin. With this arrangement no pulses were observed after the deuteron bombardment was stopped. However, when a bottle containing about 100 grams of uranium nitrate was placed between the source

and the chamber, neutrons were observed as long as $1\frac{1}{2}$ minutes after the bombardment of the uranium, the initial intensity being about one neutron per second. The decay period of these neutrons was observed to be 12.5 ± 3 sec.

Since delayed neutron emission could be due to photo-disintegration by gamma-rays we looked for and found a hard gamma-ray of approximately the same period. If these gamma-rays are the cause of the neutron emission, separate intensity tests showed that they must be at least 1000 times as effective as the lithium or fluorine gamma-rays produced by proton bombardment. No neutrons were observed with the same arrangement during proton bombardment of lithium or fluorine targets, although several photoneutrons per second were observed from a few grams of heavy water.

The period of the neutrons and gamma-rays is close to one of the beta-ray periods observed by Meitner, Hahn, and Strassmann.[1] It is possible that the gamma-ray emission follows the 10-sec. beta-ray emission observed by them, and causes or is accompanied by the emission of neutrons.

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[1] L. Meitner, O. Hahn, and F. Strassmann, Zeits. f. Physik **106**, 249–270 (1937).

Presence of the Nitrogen Forbidden Line $^2P \rightarrow {}^4S$ in the Auroral Spectrum

I have recently reported the probable presence of the N I line $^2P \rightarrow {}^4S$ in the spectrum of diffuse aurorae.[1] A preliminary study of my plates had caused me to ascribe to this radiation a wave-length near 3470A, deduced from the approximate dispersion curve given by the N_2 bands of the second positive system. However, I had also at my disposal a plate with a comparison spectrum from a small luminescence lamp containing a mixture of neon and argon. The identification of all the lines appearing on the plate enabled me to make sure that the auroral radiation practically coincides with the neon line $\lambda = 3{,}466{,}575$A, and also that, in the proper spectral region, my spectrograph is capable of distinguishing clearly lines only 3A apart. Under these conditions, I can affirm that the true wave-length of the line attributed to N I is: $\lambda = 3466.5 \pm 1$A.

This value is in good accordance with the theoretical wave-length $\lambda = 3466.6$A deduced from the ionization potential of N I (14.48 v, or 117,375 cm^{-1}, according to Hopfield). Besides, using Edlèn's still unpublished results concerning the excitation potentials of the N I levels, M. Nicolet[2] computes the value $\lambda = 3466.5$A. On the other hand, J. Kaplan[3] now finds, for the line observed by him in the laboratory, the corrected wave-length $\lambda = 3466.3$A, with an approximation of a few tenths of an angstrom. Thus, the best measurements of the lines found, near 3466A, in the afterglow and aurora spectra, indicate that their identity is highly probable, as well as the presence of ^2P nitrogen neutral atoms in the upper atmosphere.

According to B. Stepanoff,[4] the splitting of the ^2P level of N I would be nearly 2.15 cm^{-1}. It corresponds to a difference of one-fourth of an angstrom between the components of the line $^2P \rightarrow {}^4S$. Such a structure will be shown only by the interference method.

No night-sky radiation can be actually identified with the N I line $\lambda = 3466.5$A, unless by assuming an error of 4 to 5A in the measurement of the strong sky line found at $\lambda = 3471$A.

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[1] R. Bernard, Nature **141**, 1140 (1938).
[2] M. Nicolet, private communication.
[3] J. Kaplan, Phys. Rev. **54**, 541 (1938).
[4] B. Stepanoff, Phys. Zeits. Sowjetunion **8**, 353 (1935).

The Fission of Uranium*

This letter is a preliminary report of some of the experiments which we have undertaken on the fission process of the uranium nucleus by neutron bombardment.

The phenomenon was discovered by Hahn and Strassmann[1] who were led by chemical evidence to suspect the possibility of the splitting of the uranium nucleus into two approximately equal parts. Through the kindness of Professor Bohr we were informed of these results some days before receiving them in published form, as well as of the suggestion of Meitner and Frisch that the process should be connected with the release of energy of the order of 200 Mev.

It seemed worth while to attempt the detection of the fragments by their high ionization. The interior of a parallel plate ionization chamber was coated with a thin layer of uranium oxide. When this chamber was connected to a linear amplifier a large number of small pulses from the alpha-particles of uranium were observed, but when exposed to the bombardment of neutrons from the cyclotron or from a Rn-Be source very large pulses occurred in addition. From the ratio of the maxima of these large pulses to the maxima of those due to the alpha-particles it was estimated that the energies of the fragments of uranium range up to about 90 Mev. This value of the energy seems to be somewhat smaller than the theoretical expectation. If we assume that the energy release in the fission is approximately 200 Mev, and that the two fragments may have somewhat different masses, then fragments with energies up to 120 or 130 Mev might be expected in some cases. However, these values probably do not lie outside our experimental error since lack of linearity in the amplifier and incomplete collection of the ions might explain the difference.

After this experiment had been performed, Professor Bohr received a cable from Dr. Frisch stating that he had obtained the same results some days before.

A number of measurements have been made of the cross section for the fission process for neutrons of different energies. For this the interior of an ionization chamber