Delayed Neutron Emission from Uranium

Further measurements have been made on the neutron emission observed by Roberts, Meyer and Wang[1] after uranium is exposed to neutrons. In our experiments these delayed neutrons were produced by irradiating uranium with neutrons from the Be+H reaction in the cyclotron, and detected by a boron ion chamber connected to a linear amplifier-oscillograph system. Measurements with and without cadmium and boron around the uranium during irradiation showed that under these conditions the effect is produced primarily by slow neutrons and approximately follows the $1/v$ law. Decay curves were made by placing 2.5 kg of U_3O_8 inside a paraffin cylinder together with the detection chamber, and observing the boron disintegrations, after the cyclotron was turned off.

Counts per five-second interval on the oscillograph record are shown as ordinates in Fig. 1. The decay curve seems best analyzed into two periods of about 45 seconds and 10–15 seconds.

The ratio of the delayed neutron emission cross section to the uranium fission cross section was also estimated. A smaller U_3O_8 plaque (450 g) was utilized to achieve better geometrical conditions and to minimize neutron absorption. First the number of delayed neutrons from the U_3O_8 plaque, detected by the boron chamber immediately after the irradiation, was measured. For calibration of the detector, a weak Rn−Be neutron source was substituted for the U_3O_8 plaque. If the effective number of neutrons per second per mC from the Rn−Be source was 15,000 the counting system had an over-all efficiency of 1 : 2400 for neutrons emitted from the U_3O_8. The number of fissions per second from a known amount of uranium in a second detection chamber was then determined under the same geometrical conditions. The ratio of the initial number of delayed neutrons per second to the total number of fissions per second produced in the plaque was thus found to be 1 : 60. An independent check on the uranium fission cross section[2] for slow neutrons gave about 3×10^{-24} cm², and the cross section for the delayed neutron emission must therefore be about 0.05×10^{-24} cm².[3]

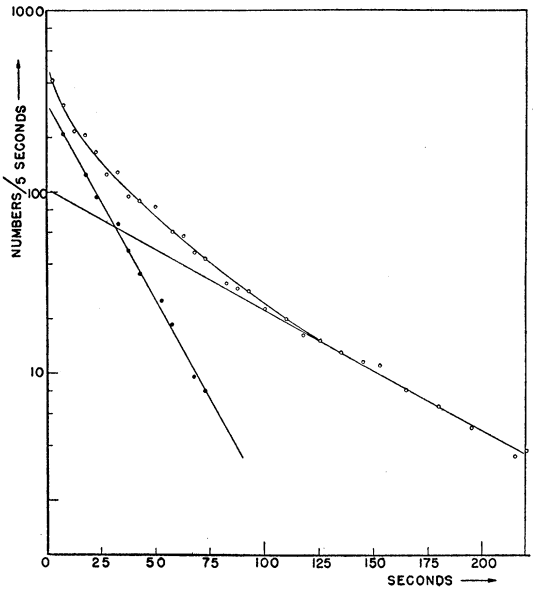

FIG. 1. Decay of delayed neutrons.

The gamma-rays emitted by uranium after neutron irradiation have also been studied. This decay curve can likewise be analyzed into periods of 10–15 seconds,[1] 40–50 seconds, together with some longer periods. Meitner, Hahn and Strassman[4] have reported beta-ray periods from uranium of 10 seconds and 40 seconds.

These observations seem to indicate that some of the fission fragments emit beta-rays with these periods and then are still sufficiently excited for the emission of gamma-ray quanta, or occasional "delayed" neutrons. It must be observed that these delayed neutrons are much less numerous than the neutrons more immediately following fissions as observed by other experimenters.[5, 6, 7]

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April 17, 1939.

[1] Roberts, Meyer and Wang, Phys. Rev. **55**, 510 (1939).
[2] Anderson, Booth, Dunning, Fermi, Glasoe and Slack, Phys. Rev. **55**, 511 (1939).
[3] Roberts, Hafstad, Meyer, Wang, Phys. Rev. **55**, 664 (1939).
[4] Meitner, Hahn and Strassmann, Zeits. f. Physik **106**, 249 (1937).
[5] von Halban, Joliot and Kowarski, Nature **143**, 470 (1939).
[6] Anderson, Fermi and Hanstein, Phys. Rev. **55**, 797 (1939).
[7] L. Szilard and W. H. Zinn, Phys. Rev. **55**, 799 (1939).

The Identification of Some of the Products of Uranium Cleavage

In a recent letter to the editor of the *Physical Review*[1] we announced the discovery of a number of antimony, tellurium and iodine isotopes formed through neutron activation of uranium. Among those active bodies was an eight-day iodine activity which was shown to be I^{131}. It was also suggested that a 70-minute tellurium body might be Te^{129}. The suggestion has been shown to be correct, and several other tellurium isotopes have been found which can be identified with known activities. These are shown in Table I.

The identification of the 70-minute body as Te^{129} rests on its half-life and on its beta-ray absorption curve. The absorption curves of the 70-minute bodies obtained by neutron activation of uranium and by deuteron activation of tellurium[2] were taken under identical geometrical conditions. The two curves were parallel over a factor of 100 in intensity. The same method was employed on the ten-hour bodies. Again the beta-ray absorption curves were found to be parallel over a factor of 100 in intensity. The parent of the ten-hour activity was isolated by separating antimony from activated uranium. Periodic tellurium extractions from the antimony showed that the half-life of the parent of the ten-hour body is 80 hours.

TABLE I.

ATOMIC WEIGHT	Sb	Te	I
131		30 hr. → 25 min.	→ 8 days 8 days
129	4.6 hr. →	70 min.	
127	82 hr. →	10 hr.	

A new piece of evidence confirms the assignment of the eight-day iodine body as I^{131}. It has been found here that the known I^{131} emits characteristic xenon x-rays. The eight-day iodine body produced from uranium likewise emits xenon x-rays.

Seaborg, Livingood and Kennedy[2] have assigned Te^{131} an isomeric pair of activities of which a 30-hour body is the higher state and a 25-minute body is the lower. These two bodies have been produced by neutron activation of uranium and their half-lives established through periodic quantitative iodine extractions from tellurium precipitated out of an activated uranium sample.

In our last communication[1] we made the following assignments of activities:

Te	I
40 min.	→ 54 min.
1 hr.	→ 22 hr.

This assignment, however, was qualified by the statement, "It is barely possible that the 22-hour activity and the 54-minute body are isomers with the 54-minute activity having the higher energy state." Further experiments now show that the 54-minute and the 22-hour bodies are not isomers and that the assignment made above is correct.

A more detailed account of these and previous experiments will be given in a paper which will appear soon. This work has been expedited by suggestions made by Dr. E. Segrè and Dr. G. T. Seaborg. I wish to express my thanks to Professor E. O. Lawrence for his interest in this experiment and to the Research Corporation for financial support.

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[1] P. Abelson, Phys. Rev. **55**, 670 (1939).
[2] G. T. Seaborg, J. J. Livingood and J. H. Kennedy, Phys. Rev. **55**, 794 (1939).

Search for Beta-Particles Emitted During Uranium Fission Process

The large energy release associated with the neutron induced uranium fission process[1] might suggest that very energetic beta-particles could be emitted during or shortly after the disintegration. We have made a search for such particles using two Geiger-Müller counters in a coincidence arrangement placed near 400 g of freshly purified U_3O_8 in which several thousand fissions per minute were being produced by irradiation with paraffin-slowed neutrons from a Ra—Be source. With 1.3 cm of aluminum between the counters no effect was observed; this is in agreement with the recent report by Heyn, Aten and Bakker[2] who found no beta-particles of energy exceeding 10 Mev.

An extension of the above type of experiment to include particles of lower energy would merely reveal the presence of recoil electrons from capture gamma-rays and the beta-particles from the short-lived activities which are known to be present. The possibility of the emission of beta-particles (of lower energies) *simultaneous* with the fission process is still interesting because such emission would lower the neutron excess in the primary products. That this process does not occur during the majority of the fissions is shown in the following experiment. A tube counter of the proportional type with a thin layer of U_3O_8 on the inner wall and an ordinary Geiger-Müller counter were placed side by side near a paraffin-encased neutron source and connected to a circuit designed to count coincidences between the very large "explosion" kicks in the one counter and beta-particles in the other. Extremely few réal coincidences were observed; the intensity of the neutron source and the geometry employed were such that we can conclude that in at least 90 percent of the fissions no electrons of energy greater than 1 Mev are emitted within the resolving time of the coincidence circuit (about 10^{-6} sec.). That coincidences could have been counted by this method was proved by using the same circuits to record coincidences between the beta-particles of ThC and the immediately following alpha-particles from ThC' ($T\frac{1}{2}\sim10^{-11}$ sec.).

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[1] O. Hahn and F. Strassmann, Naturwiss. **27**, 11 (1939) and numerous subsequent reports.
[2] F. A. Heyn, A. H. W. Aten, Jr., and C. J. Bakker, Nature **143**, 516 (1939).

Erratum: The Scattering of Alpha-Particles by Argon, Oxygen, and Neon

(Phys. Rev. **54**, 1011 (1938))

Dr. M. M. Rogers has kindly called my attention to some errors in calculation of the nuclear radii given in the above paper. The value given for the oxygen nucleus should be $3.5(10^{-13})$ cm instead of $4.5(10^{-13})$ cm, and that given for the neon nucleus (Ne^{20}) should be $4.0(10^{-13})$ cm instead of $4.6(10^{-13})$ cm.

These were calculated from the Gamow penetration formula on the assumption that the penetrability of the barrier was about 10 percent at the lowest energy for which scattering anomalies were observed. The fact that the values obtained for the radii are so far from those to be expected indicates that this method of calculation is probably not valid, at least in the case of scattering at angles small compared to 180°.

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