Letters to the Editor

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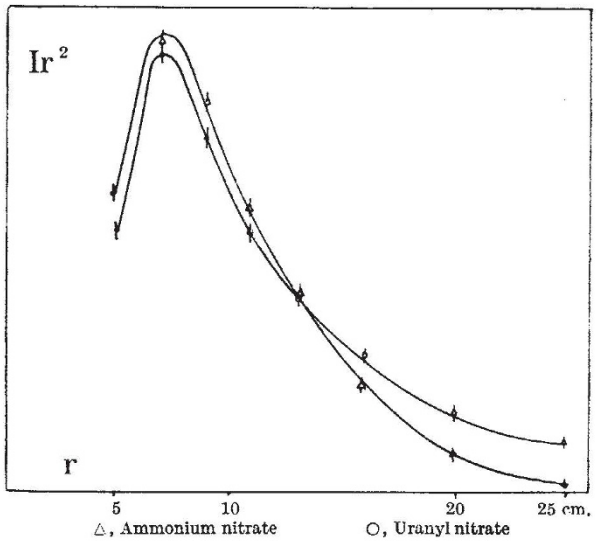
NOTES ON POINTS IN SOME OF THIS WEEK'S LETTERS APPEAR ON P. 478.

CORRESPONDENTS ARE INVITED TO ATTACH SIMILAR SUMMARIES TO THEIR COMMUNICATIONS.

Liberation of Neutrons in the Nuclear Explosion of Uranium

RECENT experiments[1,2] have revealed the existence of a new kind of nuclear reaction : neutron bombardment of uranium and thorium leads to an explosion of the nucleus, which splits up into particles of inferior charge and weight, a considerable amount of energy being liberated in this process. Assuming a partition into two particles only, so that the nuclear mass and charge of uranium have to be distributed between two lighter nuclei, the latter contain considerably more neutrons than the heaviest stable isotopes with the same nuclear charges. (A splitting into, for example, ^{98}Rb and ^{141}Cs means an excess of 11 neutrons in the first, and of 8 neutrons in the second of these two nuclei.) There seem to be two possibilities of getting rid of this neutron excess. By the emission of a β-ray, a neutron is transformed into a proton, thus reducing the neutron excess by two units ; in the example given above, five and four successive β-activities respectively would be needed to restore the neutron-proton stability ratio. In fact, the explosion products have been observed to be β-active and several periods have been recorded, so that a part, at least, of the neutron excess is certainly disposed of in this way. Another possible process is the direct liberation of neutrons, taking place either as a part of the explosion itself, or as an 'evaporation' from the resulting nuclei which would be formed in an excited state.

In order to find some evidence of this second phenomenon, we studied the density distribution of the thermal neutrons produced by the slowing down of photo-neutrons from a Ra γ - Be source in a 1·6 molar solution of uranyl nitrate and in a 1·6 molar solution of ammonium nitrate (the hydrogen contents of these two solutions differ by only 2 per cent). Plotting Ir^2 as a function of r (where r is the distance between the source and a given point, and I is the local density of thermal neutrons at the same point, measured by the activity induced in a dysprosium detector), a curve is obtained the area of which is proportional to $Q.\tau$, Q being the number of neutrons per second emitted by the source or formed in the solution and τ the mean time a neutron spends in the solution before being captured[3,4]. Any additional nuclei, which do not produce neutrons, brought into the solution, will increase the chances of capture and therefore decrease τ and the area. If, however, these dissolved nuclei are neutron-producing, Q will be greater and the area of the curve will tend to increase. Evidence of neutron production, as indicated by an actual increase of the area, will only be obtained if the gain through Q (neutron production) is greater than the loss through τ (neutron capture). This loss can anyway be studied separately, since it has been shown[5] that the introduction of nuclei which act merely by capture or by increasing the hydrogen content of the solution can affect the shape of the density curve only in a characteristic way : the modified curve can always be brought to coincide with the primitive curve by multiplying all abscissæ by a suitable factor and all ordinates by another factor.



The accompanying graph shows the two curves obtained. At small distances from the source the neutron density is greater in the ammonium solution than in the uranyl solution ; at distances greater than 13 cm., the reverse is true. In other words, the decrease of the neutron density with the distance is appreciably slower in the uranyl solution.

The observed difference must be ascribed to the presence of uranium. Since the two curves cannot be brought to coincide by the transformation mentioned above, the uranium nuclei do not act by capture only ; an *elastic* diffusion by uranium nuclei would have an opposite effect : it would 'contract' the abscissæ, instead of stretching them. The density excess, shown by the uranyl curve beyond 13 cm., must therefore be considered as a proof of neutron production due to an interaction between the primary neutrons and the uranium nuclei. A reaction of the well-known $(n,2n)$ type is excluded because our primary neutrons are too slow for such a reaction (90 per cent of Ra + Be photo-neutrons have energies smaller than 0·5 Mev. and the remaining 10 per cent are slower than 1 Mev.).

The degree of precision of the experiment does not permit us to attribute any significance to the small increase of the area in the uranyl curve (as compared to the ammonium curve), which we obtain by extrapolating the curves towards greater distances. In any event, an inferior limit for the cross-section for the production of a neutron can be obtained by

assuming that the density excess due to this production is equal throughout the whole curve to the excess observed at $r = 25$ cm.; this limit, certainly inferior to the actual value, is 6×10^{-25} cm.[2].

Our measurements yield no information on the energy of the neutrons produced. If, among these neutrons, some possess an energy superior to 2 Mev., one might hope to detect them by a (n,p) process, for example, by the $^{32}S(n,p)^{32}P$ reaction. An experiment of this kind, Ra γ - Be still being used as the primary neutron source, is under way.

The interest of the phenomenon observed as a step towards the production of exo-energetic transmutation chains is evident. However, in order to establish such a chain, more than one neutron must be produced for each neutron absorbed. This seems to be the case, since the cross-section for the liberation of a neutron seems to be greater than the cross-section for the production of an explosion. Experiments with solutions of varying concentration will give information on this question.

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March 8.

[1] Joliot, F., *C.R.*, **208**, 341 (1939).
[2] Frisch, O. R., NATURE, **143**. 276 (1939).
[3] Amaldi, E., and Fermi, E., *Phys. Rev.* **50**, 899 (1936).
[4] Amaldi, E., Hafstad, L., and Tuve, M., *Phys. Rev.*, **51**, 896 (1937).
[5] Frisch, O. R., von Halban, jun., H., and Koch, J., *Danske Videnskab. Kab.*, **15**, 10 (1938).

Products of the Fission of the Uranium Nucleus

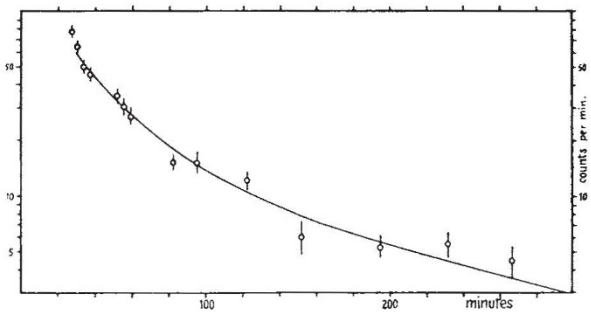
O. Hahn and F. Strassmann[1] have discovered a new type of nuclear reaction, the splitting into two smaller nuclei of the nuclei of uranium and thorium under neutron bombardment. Thus they demonstrated the production of nuclei of barium, lanthanum, strontium, yttrium, and, more recently, of xenon and cæsium.

It can be shown by simple considerations that this type of nuclear reaction may be described in an essentially classical way like the fission of a liquid drop, and that the fission products must fly apart with kinetic energies of the order of hundred million electron-volts each[2]. Evidence for these high energies was first given by O. R. Frisch[3] and almost simultaneously by a number of other investigators[4].

The possibility of making use of these high energies in order to collect the fission products in the same way as one collects the active deposit from alpha-recoil has been pointed out by L. Meitner (see ref. 3). In the meantime, F. Joliot has independently made experiments of this type[5]. We have now carried out some experiments, using the recently completed high-tension equipment of the Institute of Theoretical Physics, Copenhagen.

A thin layer of uranium hydroxide, placed at a distance of 1 mm. from a collecting surface, was exposed to neutron bombardment. The neutrons were produced by bombarding lithium or beryllium targets with deuterons of energies up to 800 kilovolts. In the first experiments, a piece of paper was used as a collecting surface (after making sure that the paper did not get active by itself under neutron bombardment). About two minutes after interrupting the irradiation, the paper was placed near a Geiger-Müller counter with aluminium walls of 0·1 mm. thickness. We found a well-measurable activity which decayed first quickly (about two minutes half-value period) and then more slowly. No attempt was made to analyse the slow decay in view of the large number of periods to be expected.

The considerable intensity, however, of the collected activity encouraged us to try to get further information by chemical separations. The simplest experiment was to apply the chemical methods which have been developed in order to separate the 'transuranium' elements from uranium and elements immediately below it[6]. The methods had to be slightly modified on account of the absence of uranium in our samples and in view of the light element activities discovered by Hahn and Strassmann[1].



In these experiments, the collecting surface was water, contained in a shallow trough of paraffin wax. After irradiation (of about one hour) a small sample of the water was evaporated on a piece of aluminium foil; its activity was found to decay to zero. It was checked in other ways, too, that the water was not contaminated by uranium. To the rest of the water we added 150 mgm. barium chloride, 15 mgm. lanthanum nitrate, 15 mgm. platinum chloride and enough hydrochloric acid to get an acid concentration of 7 per cent. Then the platinum was precipitated with hydrogen sulphide, in the usual way; the precipitate was carefully rinsed and dried and then placed near our counter.

The results of three such experiments were found to be in mutual agreement. The decay of the activity was in one case followed for 28 hours. For comparison, a sample of uranium irradiated for one hour was treated chemically in the same way. The two decay curves were in perfect agreement with one another and with an old curve obtained by Hahn, Meitner and Strassmann under the same conditions. In the accompanying diagram the circles represent our recoil experiment while the full line represents the uranium precipitate. A comparison of the activity (within the first hour after irradiation) of the precipitate and of the evaporated sample showed that the precipitate contained about two thirds of the total activity collected in the water. After about two hours, however, the evaporated sample was found to decay considerably more slowly than the precipitate, presumably on account of the more long-lived fission products found by Hahn and Strassmann[1].

From these results, it can be concluded that the 'transuranium' nuclei originate by fission of the uranium nucleus. Mere capture of a neutron would give so little kinetic energy to the nucleus that only a vanishing fraction of these nuclei could reach the water surface. So it appears that the 'transuranium'