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CONTRIBUTION OF 238 FISSION TO THE

FAST CHAIN REACTION IN ENRICHED MIXTURES

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The neutron balance in a fast neutron chain reaction maintained in a large mass of uranium enriched in 49 depends primarily on the number of neutrons emitted in the fission of 49 and on the contribution of fission of U^{238} to the chain reaction. The most favorable case for a maximum contribution of U^{238} is the case of a mixture of U^{238} with a small amount of 49 in the absence of any other elements which might slow down, by inelastic collisions or otherwise, neutrons.

The contribution of U^{238} fission to such a fast neutron chain reaction can be estimated on the basis of two experiments in the following manner:

A sphere of uranium which is covered by cadmium is placed in the center of a spherical cavity in a large paraffin block. A radium-boron neutron source is placed in the center of the uranium sphere and by measuring the intensity of the indium resonance neutrons in the paraffin the total number of neutrons emerging from the uranium sphere is compared with the number of neutrons emitted from the radium-boron source in the absence of the uranium sphere. A measurement of this type carried out by the group of B. Feld gave, for a given sized uranium sphere, an increase in the number of neutrons by a factor of $\mathcal{E} = 1.053$. This increase is due to neutrons produced in U^{238} by the boron neutrons.

Another experiment carried out with the same uranium sphere was made in the following way: A radium-boron source was placed in the center of the uranium sphere which was supported free in air removed from the walls and other scattering material and the number of fissions caused by the radium-boron neutrons which emerged from the uranium sphere was observed. This number was found to be about α = .63% of the number obtained from the radium-boron source in the absence of the uranium sphere.

From these two experiments we can now estimate if we make certain simplifying assumptions what would be the number of ε α neutrons liberated from U^{238} if one fast fission neutron were released in an infinite mass of uranium. In order to be able to conclude from these two experiments we have to assume that for the purposes of this estimate the spectrum of the fission neutrons is identical with the spectrum of the radium-boron neutrons. We have further to assume that the properties of the neutron radiation which emerges from the uranium sphere and the properties of the neutron radiation emitted by the radium-boron source do not appreciably differ with respect to causing fission in U^{238} and with respect to undergoing inelastic collision in U^{238} . If these assumptions are made we may write for the total number of neutrons that would be liberated by fission neutron in an infinite mass of U^{238}

This is probably a pessimistic estimate and the number to be expected is larger for the following reasons: By comparing radium-beryllium neutrons with radium-boron neutrons it was found that these two neutron spectra do not appreciably differ with respect to cross section for inelastic collision in U^{238} or with respect to fission cross section in U^{238}. Nevertheless the increase in the number of neutrons caused by the uranium sphere is about twice as large for radium-beryllium neutrons than for radium-boron neutrons and this must be interpreted by assuming that the number of excess neutrons (γ - 1) liberated by radium-beryllium neutrons is about twice as large than for radium-boron neutrons. This does not necessarily mean that the number of neutrons emitted in connection with fission is actually larger by this factor for radium-beryllium neutrons since we cannot exclude the possibility of an n - 2n reaction in U^{238}. An increase in the number of neutrons per fission with increasing neutron energy can come about in either of two ways. The neutron can suffer an inelastic collision in U^{238} and may leave behind a U^{238} nucleus sufficiently highly excited to undergo fission and this would simulate an apparent increase in   or there may be a genuine increase in   inasmuch as a faster neutron may, if captured, get to a highly excited U^{239} nucleus which may disintegrate with the emission of a larger number of neutrons.

The fission neutrons from thermal fission of U^{235} appear to reach appreciably higher energies than the radium-boron neutrons though they are on the whole less energetic than the radium-beryllium neutrons. This contention is supported by a comparison of the radioactivities induced by these three categories of neutrons by means of n - p, n -   which was carried out by B. Feld's group. In the circumstances, we would probably underestimate the value of ε for fission neutron if we used the value of   =   taken from the experiment with radium-boron neutrons. The value of ε = 1.187, which is close to the upper limit but within the experimental accuracy still consistent with the measurement carried out for radium-boron neutrons, may until further notice be used as a sort of conventional value which is most likely still too low for fission neutrons and therefore on the conservative side.

Contribution of 238 fission to the fast chain reaction in enriched mixtures. —

~~Memorandum~~

December 1, 1943
L. Szilard

The neutron balance in a fast neutron chain reaction maintained in a large mass of uranium enriched in 49 depends primarily on the number of neutrons emitted in the fission of 49 and on the contribution of fission of U^{238} to the chain reaction. The most favorable case for a maximum contribution of U^{238} is the case of a mixture of U^{238} with a small amount of 49 ~~in~~ and the absence of any other elements which might slow down neutrons (by inelastic collisions or otherwise).

The contribution of U^{238} fission to such a fast neutron chain reaction can be estimated (on the basis of two experiments) in the following manner:

~~The~~ a sphere of uranium (which is covered by Cadmium) is placed in the center of a spherical cavity in a large paraffin block. A radium-boron neutron source is placed in the center of the uranium sphere and by measuring the intensity of the indium resonance neutrons in the paraffin the total number of neutrons emerging from the uranium sphere is compared with the number of neutrons emitted from the radium boron source in the absence of the uranium sphere. A measurement of this type carried out by the group of B. Feld gave, for a given sized uranium sphere, an increase in the number of neutrons by a factor of $\varepsilon =$ 1.053. This increase is due to ~~fission~~ neutrons produced in U^{238} by the radium-boron neutrons.

Another experiment carried out with the same uranium sphere was made in the following way: A radium-boron source was placed in the center of the uranium sphere which was supported free in ~~space~~ air removed from the walls and other scattering material and the number of fissions caused by the radium-boron neutrons which emerged from the uranium sphere was observed.

$\alpha =$

This number was found to be about .63% of the number obtained from the radium-boron source in the absence of the uranium sphere. From these two results we can now estimate if we make certain assumptions which will be specified below the number of neutrons which will be liberated from U^{238} if a fast fission neutron is released in an infinite mass of uranium. In order to be able to conclude for our experiments we have to assume that for our purposes the spectrum of the fission neutron is sufficiently similar to the spectrum of the radium-boron neutrons and also that the properties of the radiation which emerges from the uranium sphere does not appreciably differ with respect to causing fission in U^{238} and with respect to inelastic collision in U^{238} from the property of the neutron radiation emitted by the radium-boron source. If these assumptions are made we may write for the total number of neutrons that would be liberated by fission neutron in an infinite mass of U^{238}

$$\varepsilon_\infty - 1 = \varepsilon - 1 + \alpha(\varepsilon - 1) + \alpha^2(\varepsilon - 1) + \cdots \alpha^n(\varepsilon - 1) = (\varepsilon - 1)\frac{1}{1-\alpha}$$

and for $\varepsilon - 1 = 0.053$; $\alpha = 0.63$; $\varepsilon_\infty = 1.96$

This is probably a pessimistic estimate and the number to be expected is larger for the following reasons: By comparing radium-beryllium neutrons with radium-boron neutrons it was found that these two neutron spectra do not appreciably differ with respect to cross section for inelastic collision in U^{238} or with respect to fission cross section in U^{238}. Nevertheless the increase in the number of neutrons caused by the uranium sphere is about twice as large for radium-beryllium neutrons than for radium-boron neutrons and this must be interpreted by assuming that the number of excess neutrons ($\nu - 1$) liberated by radium-beryllium neutrons is about twice as large than for radium-boron neutrons. This does not necessarily mean that the number of neutrons emitted per fission is actually

$> (\varepsilon - 1) + \alpha(\varepsilon - 1)$

larger by this factor for radium beryllium neutrons since we cannot exclude the possibility of an ~~end to end~~ n-2n reaction in U^{238}. An increase in the number of neutrons per fission with increasing neutron energy (is however likely and) can come about in either of two ways. The neutron can suffer an irelastic collision in U^{238} and may leave behind a U^{238} nucleus sufficiently highly excited to undergo fission and this would simulate an apparent increase in ν or there may be a genuine increase in ν inasmuch as a faster neutron may, if captured, get to a highly excited U^{239} nucleus which may disintegrate with the emission of a larger number of neutrons. [The existence of] Either of these two mechanisms would lead us to expect that fission neutrons will liberate a larger number of neutrons in a large mass of U^{238} than would radium-boron neutrons since The reason for this expectation is the fact that experiments in which the intensity of various N -   and N - p processes were observed for radium-boron. U^{235} fission and radium-beryllium neutrons showed that those processes would require high energies or more strongly excited by radium-beryllium neutrons than by radium-boron neutrons and that the fission neutrons from U^{235} were in between these two types of neutrons. Until further evidence becomes available we shall use therefore a somewhat higher value for   than the value given above, namely the value of

    , which represents something like the upper limit for radium-boron neutrons that would still be consistent with the experiments performed with that type of neutron reaction.

[~~Since~~ The] fission neutrons (formed from U^{235}) appear to ~~the~~ reach to appreciably ~~considerably~~ higher energies than ~~the~~ the ~~boron-rad~~ radium boron neutron spectrum, though not quite as high as the ~~ra~~ ~~rather~~ radium beryllium neutron spectrum. This ~~view~~ anticipation is supported by a comparison of the relative intensities...