665-39

November 14, 1941

PRELIMINARY REPORT ON FISSION
CAUSED BY FISSION NEUTRONS

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It appeared to be ~~important~~ of interest to determine whether fission can be caused in uranium by fission neutrons and if so to learn something about the cross-section of this process.

This process may play an important role in a chain reaction in a system in which spheres of uranium are imbedded in a large mass of graphite. In such a system thermal neutrons diffuse from the graphite into the uranium sphere and lead to the emission of fast fission neutrons. The fast neutrons thus produced will cause a certain number of fission processes in the same uranium sphere from which they originate and thus produce secondary fast fission neutrons. Some of these secondary neutrons will again cause fission in the uranium sphere from which they originate and lead to tertiary fission neutrons, etc. This process might increase by perhaps ~~as much as a~~ a factor of $\beta = 1.25$ the number of fast neutrons emitted by uranium per thermal neutron absorbed by uranium. The magnitude of the factor β depends primarily upon certain nuclear properties of uranium and in the first approximation on the product

$$\sigma_f(\nu-1)$$

where σ_f is the cross-section of uranium for fast fission neutrons and ν is the number of neutrons emitted per fission process. The magnitude of the factor β also depends on the cross-section of uranium for inelastic collisions which slow down fast fission neutrons below the fission threshold of U238. This slowing-down phenomenon of uranium has been studied by Szilard and Zinn and will form~~s~~ the subject of another report.

Secondarily, the magnitude of the factor β depends on the size and density of the uranium sphere and also on the presence in the uranium sphere of oxygen or other elements which slow down the neutrons by means of elastic collisions. It may very well be that, due to the process which is the subject of this report, there may be a ten per cent ~~difference~~ increase in the number of fast neutrons emitted by a uranium sphere per thermal neutron absorbed by the uranium sphere if we change over from uranium oxide at a density of about 4 to 6 gm./cc. to uranium metal of density 18 to 20 gm./cc. The experiment which we performed has the purpose of measuring the quantity

$$\sigma_f \nu$$

The principle of the experiment is illustrated in the enclosed diagram which shows the experimental arrangement. In this diagram Be is a beryllium block which serves as a source of photo neutrons and which is placed in the axis of a cylindrical paraffin block. Ra represents about two grams of radium which are placed in the center of the beryllium block. A cadmium diaphragm A leaves a circular opening B free through which thermal neutrons can emerge from the paraffin and can enter in the absence of the cadmium screen ~~B~~ at H). ~~These thermal neutrons can enter~~ the cylindrical box U which contains uranium in the amount of about 25 grams per square cm. A spherical ionization chamber D which is coated with a thick layer of uranium and has a uranium-coated surface of about 800 cm. square is used to record fission which takes place in the uranium coating of this chamber. This fission chamber is protected from the action of thermal neutrons by thick ~~layers~~ walls of boron carbide, and one of the walls E is a boron carbide screen which can be removed if it is desired to admit thermal neutrons to the fission chamber.

The basic experiment which we performed is the following: With the boron screen E and the cadmium screen ~~B~~ placed placed (at H ~~in position~~, the fission chamber registers a background of about .5 fissions per minute. Thermal neutrons which come from the circular opening C in the center of the cadmium diaphragm A are prevented by the cadmium screen ~~B~~ at H from reaching the uranium during this "control" experiment. If the cadmium screen is now brought from the position ~~B~~ H into the position ~~C~~ K, thermal neutrons are admitted to the uranium, will cause fission in the uranium and will lead to the emission of fast fission neutrons. A considerable fraction of these neutrons passes through the uranium filled box U ~~whole thickness of the uranium layer~~ and through the boron screen E and will cause fission in the ~~fission~~ ionisation chamber D. By changing the position of the cadmium screen from position ~~B~~ H to position ~~C~~ K, we obtained a fission count which was more than double of the background count, the difference corresponding to about .7~~6~~ counts per minute. A preliminary estimate of the quantities involved leads to the conclusion that the observed effect corresponds to a value of about

$$\sigma_f \nu \cong 1.3 \times 10^{-24}\ \text{cm}^2$$

Taking for ν the value of 2.6 reported by Zinn and Szilard,* we obtain

$$\sigma_f = 0.5 \times 10^{-24}\ ;\ \sigma_f(\nu - 1) = 0.8 \times 10^{-24}$$

It has to be emphasied that this is a preliminary result, and that ~~the experiments will be repeated, and that~~ an attempt will be made to determine the value more accurately than it was possible to do in the first rough experiment.

In the following we describe two methods which were used in interpreting the observed effect. The following designations will be used:

F_f is the fission count which we obtain from the fast neutrons when we remove the cadmium screen ~~B~~ at H

F_{th} is the fission count which we obtain in the chamber (in the absence of the uranium, the cadmium screen at ~~B~~ or at ~~C~~ and the boron screen E) due to the action of thermal neutrons which emerge from the window G in the center of cadmium diaphragm A, and which can be cut off by placing the cadmium screen in the position ~~B~~ H.

N is the number of thermal neutrons which emerge from the circular window G in the center of the cadmium diaphragm A.

α is ~~the~~ the fraction of these thermal neutrons which are absorbed by the uranium in the box U.

1 - ε is the fraction of the fast neutrons which are emitted by uranium and which are prevented from reaching the ionization chamber by scattering either ~~in~~ by uranium in the box U ~~or by~~ ~~B or C~~ in the boron while screen E.

* Zinn & Szilard Phys. Rev. 1939

~~N N~~ N $b/2\pi$ is the number of thermal neutrons emitted (per unit solid angle) from the paraffin wall in the circular opening G ~~in the center of the cadmium diaphragm A~~ in the forward direction (towards the chamber D) ~~per unit solid angle~~.

U is the number of uranium atoms which are exposed to the thermal neutrons.

ρ is the thermal neutron density ~~of~~ in the uranium.

r is the distance of a volume element of uranium in the Box U ~~G~~ from a surface element of the uranium layer in the spherical ionization chamber.

σ_{th} ~~(fission)~~ (fiss.) is the fission cross-section of uranium for thermal neutrons.

σ_{th} is the total absorption cross-section of uranium for thermal neutrons.

ρ_0 is a thermal neutron density ~~XXXXX~~ at the location of the uranium surface of the spherical ionization chamber in the absence of the uranium~~, Box G~~ box U, the cadmium screens ~~B~~ H and ~~C~~ K and the boron screen E.

The main quantities which we measure are F_{th} and F_f. One of the methods employed makes use of the fact that we may write:

$$F_{th} = \frac{N b}{2\pi \overline{r^2_{th}}} \sigma_{th}(\text{fission})\, n^{th}$$

$$F_f = \frac{N}{4\pi \overline{r_f^2}} \alpha \varepsilon \frac{\sigma^{th}(\text{fission})}{\sigma^{th}} (\sigma^f V)\, n^f$$

or

$$\sigma^f V = \frac{F_f}{F_{th}} \sigma_{th} \frac{2b}{\alpha \varepsilon} \frac{n^{th}}{n^f} \frac{\overline{r_f^2}}{\overline{r_{th}^2}} \qquad (1)$$

In these formulae n^{th} ~~$N_{th}(U)$~~ is the number of uranium atoms which is effective in producing an impulse in the chamber if excited by thermal neutrons, and nf ~~$N_f(U)$~~ is the number of uranium atoms which is effective in producing an impulse in the chamber if excited by fast fission neutrons. We ~~have actually~~ shall assume~~d~~ that these two numbers are actually equal, i.e., that the range of the fission particles is about the same when the fission is due to thermal neutrons as it is when the fission is due to fast fission neutrons.

~~From these two equations, we obtain:~~

about 500 counts
250 counts

Our experiments gave for F_{th} a value of 43 counts per minute (cadmium difference), and for F_f we obtained from 25 fifteen-minute readings with the cadmium screen at the position H and K, ~~respectively~~ each, a value of ~~0.77~~

$Ff = 0.77$ count/min

above a background count of .6 per minute.

α, the fraction of thermal neutrons which are absorbed by the uranium in the box, was estimated to be about 0.5 The uranium box contains about 27.7 gms./sq.cm. of uranium carbide or about 25.2 gms./sq.cm. of uranium. If we Neglect~~ing~~ ex scattering of the thermal neutrons, then we should expect that of the thermal neutrons passing through the uranium box parallel to the axis of the arrangement, a fraction of .31 would be absorbed, and a fraction of .687 would be transmitted by the uranium box. By measuring the thermal neutron density with a vanadium indicator in front and right behind the uranium box, we find that the thermal neutron density actually drops in the uranium box by a factor of 8~~, in our arrangement.~~ Part of this large drop is due to the scattering of thermal neutrons in the uranium box, ~~and~~ and part of it is due to oblique passage a very rough estimate leads us to believe that actually about .5 of the neutrons entering the uranium box are absorbed.

For b we take the value of

$$b = 2.53$$

which corresponds to ~~distribution of~~ an angular distribution of

$$\cos\varphi + \sqrt{3} \times \cos^2\varphi$$

~~for the~~ angular ~~spatial distribution~~ of thermal neutrons leaving the paraffin window G inside the cadmium diaphragm A.

For ε we took the value of .75 by estimating the effect of the scattering in the boron carbide screen E containing 3 gms./sq.cm. of boron carbide and the effect of scattering of the uranium carbide in the uranium box.

For $\frac{\overline{r_f^2}}{r_{th}^2}$ we took the value of $\left(\frac{13}{14}\right)^2 = 0.87$

For σ^{th} we took the value of 5.9×10^{-24} sq.cm.

With these values we obtained from (1)

$$\sigma_f V = 1.24$$

The second method employed makes use of the fact that we may write

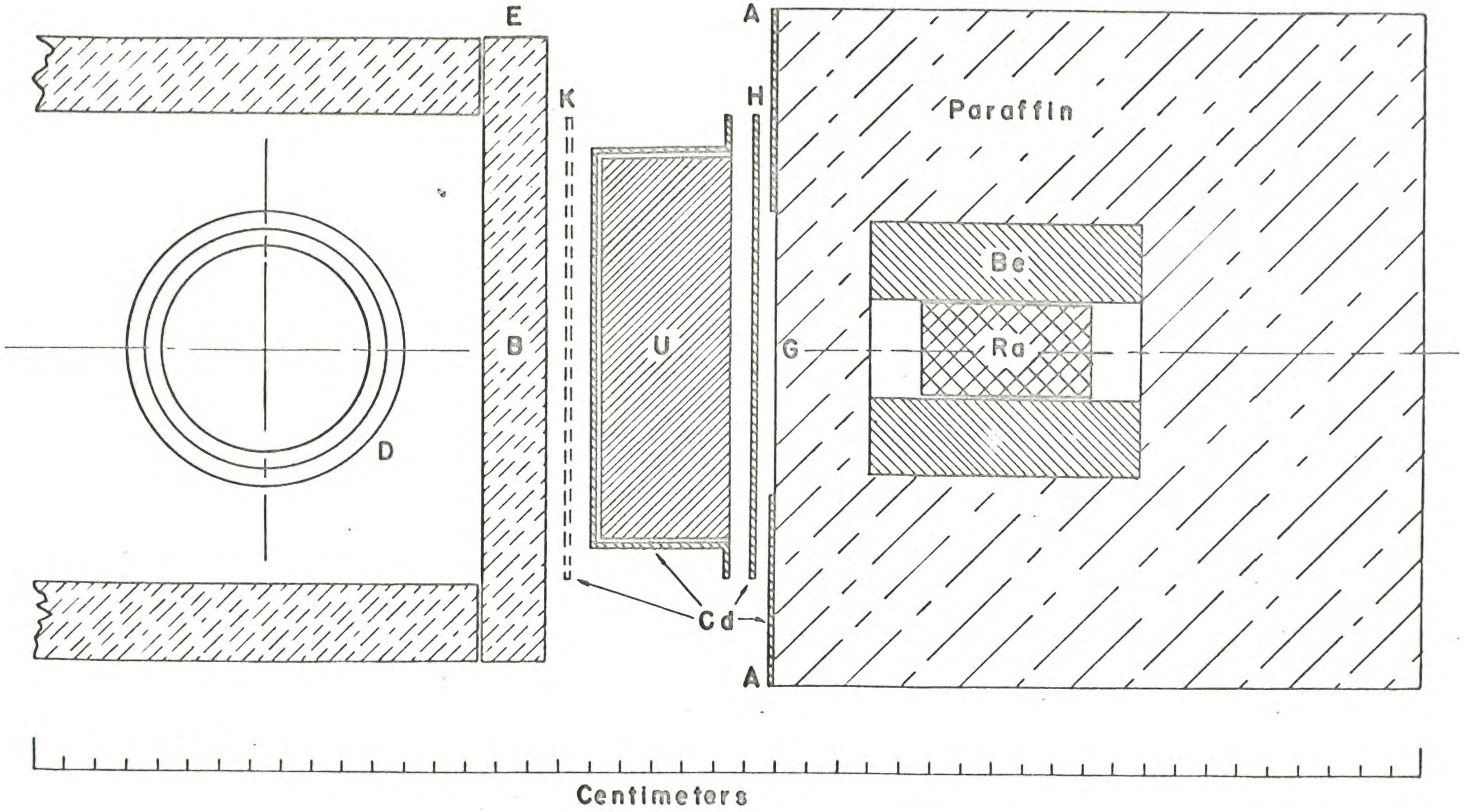
$$\sigma_f V = 4\pi\overline{\rho_0}\,\overline{\left(\frac{r_f^2}{\rho}\right)}\,\frac{1}{U}\,\frac{1}{\varepsilon}\,\frac{F^f}{F^{th}}\,\frac{n^{th}}{n^f} \tag{2}$$

We estimated ρ inside the uranium, and ρ_0, the thermal neutron density in the space occupied by the ionization chamber D by observing the activity of a vanadium foil in front of the window G on both sides of the uranium box and also in the absence of the uranium box, the cadmium screens at H or K and the boron screen E with a vanadium foil taking the place of the ionization chamber D. Assuming an exponential fall of the thermal neutron density inside the uranium box, we then find for $4\pi \rho_0 \left(\frac{r_f^2}{\rho}\right) = (4\pi r_f^2) \frac{\rho_0}{\rho} = 250$

For the number of uranium atoms in front of the window G we take the number ~~of~~ U = 4.63×10^{24} corresponding to 1830 gms. of uranium. For ε we again take the value of 0.75

With these values we obtain from (2)

(2)a) $\sigma_f V = 1.28$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