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# Neutron Production and Absorption in Uranium*

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IT has been found[1–3] that there is an abundant emission of neutrons from uranium under the action of slow neutrons, and it is of interest to ascertain whether and to what extent the number of neutrons emitted exceeds the number absorbed.

This question can be investigated by placing a photo-neutron source in the center of a large water tank and comparing, with and without uranium in the water, the number of thermal neutrons present in the water. In the previous experiments of this type[1, 3] it was attempted to have as closely as possible a spherically symmetrical distribution of neutrons. The number of thermal neutrons present in the water was determined by measuring along one radius the neutron density $\rho$ as a function of the distance $r$ from the center, and then calculating $\int r^2 \rho dr$. A difference in favor of uranium of about five percent was reported by von Halban, Joliot and Kovarski.[4]

Since one has to measure a small difference, slight deviations from a spherically symmetrical distribution might give misleading results. The present experiments which are based on the same general principle do not require such symmetry. In order to measure the number of thermal neutrons in the water we filled the tank with a ten-percent solution of $MnSO_4$. The activity induced in manganese is proportional to the number of thermal neutrons present. A physical averaging was performed by stirring the solution before measuring the activity of a sample with an ionization chamber. To obtain an effect of sufficient magnitude, about 200 kg of $U_3O_8$ was used.

The experimental arrangement is shown in Fig. 1. A photo-neutron source, consisting of about 2 g of radium and 250 g of beryllium was placed in the center of the tank. The geometry was such that practically all neutrons emitted by the source and by the uranium oxide were slowed down and absorbed within the tank. Each irradiation extended over several half-life periods of radiomanganese and the observed activity of the solution was about four times the background of the ionization chamber. Alternating measurements were taken with the cans filled with uranium oxide, and with empty cans of the same dimensions. The activity proved to be about ten percent higher with uranium oxide than without it. This result shows that in our arrangement more neutrons are emitted by uranium than are absorbed by uranium.

In order to find the average number of fast neutrons emitted by uranium for each thermal neutron absorbed by uranium, we have to determine what fraction of the total number of neutrons emitted by the photo-neutron source is, in our experiment, absorbed in the thermal region by uranium. The number of photo-neutrons

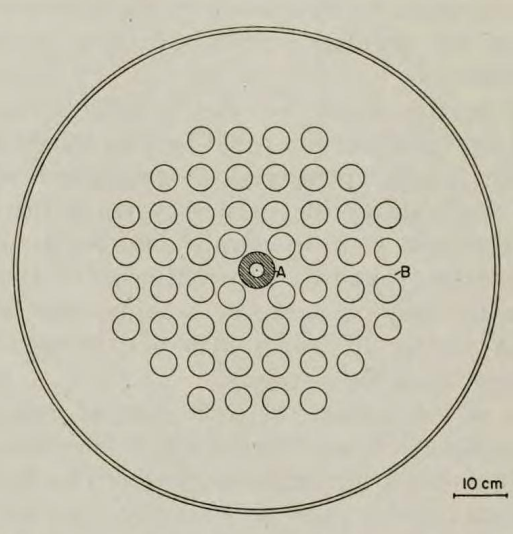


FIG. 1. Horizontal section through center of cylindrical tank which is filled with 540 liters of 10-percent $MnSO_4$ solution. A, Photo-neutron source composed of 2.3 grams of radium and 250 grams of beryllium. B, One of 52 cylindrical cans 5 cm in diameter and 60 cm in height, which are either empty or filled with uranium oxide.

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[1] v. Halban, Joliot and Kovarski, Nature **143**, 470 (1939).

[2] L. Szilard and W. H. Zinn, Phys. Rev. **55**, 799 (1939).

[3] Anderson, Fermi and Hanstein, Phys. Rev. **55**, 797 (1939).

[4] v. Halban, Joliot and Kovarski, Nature **143**, 680 (1939).

emitted by the source is indicated by the activity of the solution in the tank when the irradiation is carried out with empty cans surrounding the source. We obtained a measure of this number by taking into account that in our solution about 20 percent of the neutrons are captured by manganese and the rest by hydrogen. In order to obtain, in the same units, a measure of the number of neutrons absorbed by uranium we proceeded in the following way: A mixture of sand and manganese powder, having the same thermal neutron absorption as uranium oxide replaced the uranium oxide in $\frac{1}{4}$ of the cans which were distributed uniformly among the other uranium oxide-filled cans. After irradiation, all this powder was mixed together, a ten-percent $MnSO_4$ solution was prepared from a sample, and its activity was measured with our ionization chamber.

In this way we found that about 50 percent of the neutrons emitted by the source are absorbed as thermal neutrons by uranium in our arrangement. It follows that, if uranium absorbed only thermal neutrons, the observed ten-percent increase in activity obtained with uranium present would correspond to an average emission of about 1.2 neutrons per thermal neutron absorbed by uranium. This number should be increased, to perhaps 1.5, by taking into account the neutrons which, in our particular arrangement, are absorbed at resonance in the nonthermal region by uranium, without causing neutron emission.

From this result we may conclude that a nuclear chain reaction could be maintained in a system in which neutrons are slowed down without much absorption until they reach thermal energies and are then mostly absorbed by uranium rather than by another element. It remains an open question, however, whether this holds for a system in which hydrogen is used for slowing down the neutrons.

In such a system the absorption of neutrons takes place in three different ways: The neutrons are absorbed at thermal energies, both by hydrogen and uranium, and they are also absorbed by uranium at resonance before they are slowed down to thermal energies. Our result is independent of the ratio of the concentrations of hydrogen and uranium, insofar as it shows that, for thermal neutrons, the ratio of the cross section for neutron production and neutron absorption in uranium is greater than one, and probably about 1.5. What fraction of the neutrons will reach thermal energies without being absorbed will, however, depend on the ratio of the average concentrations of hydrogen and uranium. Since there is an appreciable absorption even far from the center of the resonance band, it follows that the fraction of neutrons absorbed by uranium at resonance will increase with decreasing hydrogen concentration. This has to be taken into account in discussing the possibility of a nuclear chain reaction in a system composed essentially of uranium and hydrogen. A chain reaction would require that more neutrons be produced by uranium than absorbed by uranium and hydrogen together. In our experiment the ratio of the average concentration of hydrogen to uranium atoms was 17 to 1, and in the experiment of von Halban, Joliot and Kovarski this ratio was 70 to 1. At such concentrations the absorption of hydrogen in the thermal region will prevent a chain reaction. By reducing the concentration of hydrogen one would obtain the following effect: On the one hand a larger fraction of those neutrons which reach thermal energies will be absorbed by uranium; on the other hand fewer neutrons reach the thermal region due to an increased absorption by uranium at resonance. Of these two counteracting factors the first is more important for high hydrogen concentrations and the second is more important for low hydrogen concentrations. Starting with high hydrogen concentrations, the ratio of neutron production to total neutron absorption will thus first rise, then pass through a maximum, and, as the hydrogen concentration is decreased, thereafter decrease. We attempted to estimate the quantities involved from the information available about resonance absorption in uranium[5–7] and from the observed net gain of 0.2 in the number of neutrons in our experiment. The effect of the absorption at resonance turns out to be so

[5] Meitner, Hahn and Strassman, Zeits. f. Physik **106**, 249 (1937).

[6] v. Halban, Kovarski and Savitch, Comptes rendus **208**, 1396 (1939).

[7] H. L. Anderson and E. Fermi, Phys. Rev. **55**, 1106 (1939).

large that even at the optimum concentration of hydrogen it is at present quite uncertain whether neutron production will exceed the total neutron absorption. More information concerning the resonance absorption of uranium as well as more accurate measurement of some of the values which enter into our calculation are required before we can conclude whether a chain reaction is possible in mixtures of uranium and water.

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