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Divergent Chain Reaction In Systems Composed Of Uranium And Carbon

INTRODUCTION 1

As early as 1913 H. G. Wells forecast the discovery of induced radio-activity for the year 1933 and described the subsequent advent of nuclear transmutations on an industrial scale. It was not possible for physicists to realize the potentialities and the limitation of nuclear physics in this direction until after the discovery of the neutron in 1932. Owing to the discovery of artificial radio-activity in 1933 by Joliot and Irene Curie, and Fermi's pioneer work on neutron reactions in 1934, progress in the field of nuclear physics was greatly accelerated. By the middle of 1934 it could be clearly seen that within the framework of modern nuclear physics transmutation of elements on an industrial scale might be achieved by means of a chain reaction in which neutrons form the links of the chain. If there is an element or a mixture of elements which interacts with neutrons and from which a neutron liberates on the average more than one neutron for one neutron which is absorbed within the mixture we have a chain reaction and may bring about nuclear transmutations on a large scale. If a neutron source is placed in the center of a large sphere which is composed of such an element or mixture the number of neutrons emerging out of the sphere will be larger than the number of neutrons emitted by the source in the center of the sphere. If the radius of the sphere approached a certain critical radius the number of neutrons generated in the chain would tend to become infinite. If the radius of the sphere is larger than the critical radius there is no stationary solution of the equation and the number of neutrons would increase exponentially with time.

By simplifying the problem so as to be able to apply the theory of diffusion to the motion of the neutrons which are liberated in the chain reaction it is easy to get an approximate picture of the general type of behaviour of a chain reaction within a finite sphere of matter.

Such a simplified treatment has been applied to the problem as early as 1934 particularly with regard to the potential possibility of setting up a chain reaction in beryllium. At that time it appeared from Bainsbridges's value for the mass of beryllium, and Aston's value for the mass of helium, that beryllium ought to be unstable and that neutrons might be liberated from beryllium by slow neutrons in sufficient numbers to make a chain reaction possible. This idea had to be abandoned, as far as beryllium was concerned, when Aston's value for the mass of helium proved to be in error.

In 1934 the transmutation of uranium by neutrons was discovered along that of other elements by Amaldi, D' Agostino, Fermi, Rasetti, and Segre who found that a number of radioactive elements are generated from uranium by neutrons. An important advance was made by Irene Curie and P. Savitch, who found that an element which behaved chemically apparently like radium was among those produced and later Irene Curie and P. Savitch discovered radio active rare earths among the disintegration products of uranium. Finally Hahn and Strassman announced in December 1938 that in reality uranium splits into a large number of elements of medium atomic weight if irradiated by neutrons.

As soon as this became known it must have been evident to all those who had been thinking previously of the potential possibilities of a chain reaction, as well as to others, that it neutrons should be emitted from splitting uranium atoms in sufficient numbers a chain reactions might be set up in a large mass of uranium. Independently of each other a small number of physicists began therefore to prepare experiments with the aim to discover whether or not neutrons are emitted from splitting uranium.

Ideas along these lines found wider circulation in America through a semi-private meeting held in Washington in January, 1939 under the auspices of the George Washington University and the Carnegie Institute for Terrestrial Magnetism. At this meeting I understand, Fermi drew attention to the potential possibility of a neutron emission from splitting

uranium and some of its possible consequences. For a short time afterwards it seemed that the absorption of uranium would over compensate any conceivable neutron emission since it was found [1] that the cross-section of uranium for splitting by thermal neutrons is about 2 whereas the currently accepted value for the absorption of uranium for the thermal neutrons was 45. However the absorption of uranium for thermal neutrons was thereupon remeasured by Fermi who discovered that its value was only about 3.

A delayed emission of neutrons from uranium under the action of neutrons bombardment was discovered in February 1939 by Roberts, Meyer, and Wang [2].

A much stronger instantaneous emission of neutrons by uranium under the action of thermal neutrons was discovered independently and almost simultaneously by Halban, Joliot, and Kowarski [3]; Anderson and Fermi [4]; and Szilard and Zinn [5] who reported their observations in letters to Nature and to Physical Review dated March 8, March 16, and March 16 (1939) respectively. An observation [6] pointing in the same direction was also reported by v. Droste in a letter to Die Naturwissenschaften dated March 17, (1939).

The first paper to appear in print was that of Halban, Joliot, and Kowarski which was published on Nature on March 18, (1939) A number of papers dealing with the instantaneous neutron emission of uranium were sent to periodicals after this date some of which presumably reporting experiments which were started independently at an earlier date. [7-10]

The balance of neutron absorption and emission by uranium was subsequently studied by Halban, Joliot and Kowarski [11]; Anderson, Fermi and Szilard [12]; and Halban, Joliot, Kowarski, and Perrin [13]. This work demonstrates beyond doubt that, on the average, more than one fast neutron is emitted for one thermal neutron absorbed by uranium. It shows therefore, that in certain circumstances a chain reaction might be maintained in a mixture of uranium and an element which slows down to thermal energies the fast neutrons emitted by the splitting uranium. If it is possible to avoid that too large a fraction of the fast neutrons emitted from the splitting uranium be captured (without causing fission) at resonance by uranium and if it is possible at the same time to avoid that too large a

fraction of the thermal neutrons be captured by the element which is used for the purpose of slowing down, then we would have a chain reaction which may diverge for a sufficiently large mass of uranium.

This does not necessarily mean that a chain reaction can be maintained in a mixture of uranium oxide and water. In a homogeneous mixture of uranium oxide and water a considerable fraction of the neutrons is absorbed by uranium at resonance and it remains doubtful whether in such a mixture the number of neutrons produced may exceed the number of neutrons absorbed. (9) Fermi has investigated the question whether more favorable conditions can be obtained in mixtures of uranium oxide and water by keeping the uranium oxide and water in separate layers and found that a slight improvement can thus be obtained. But even so, for the present the question whether a chain reaction can be obtained in a system composed of uranium and water is being left in abeyance.

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Note added in May 1946.

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uranium and some of its possible consequences. For a short time afterwards it seemed that the absorption of uranium would over compensate any conceivable neutron emission since it was found[1] that the cross-section of uranium for splitting by thermal neutrons is about 2, whereas the currently accepted value for the absorption of uranium for the thermal neutrons was 43. However the absorption of uranium for thermal neutrons was thereupon remeasured by Fermi who discovered that its value was only about 5.

A delayed emission of neutrons from uranium under the action of neutrons bombardment was discovered in February 1939 by Roberts, Meyer, and Wang.[2]

A much stronger instantaneous emission of neutrons by uranium under the action of thermal neutrons, was discovered independently[3] and almost simultaneously[4] by Halban, Joliot, and Kowarski; Anderson and Fermi; and Szilard and Zinn[5] who reported their observations in letters to Nature and to Physical Review dated March 8, March 16, and March 16 (1939) respectively. An observation[6] pointing in the same direction was also reported by v. Droste in a letter to Die Naturwissenschaften dated March 17, (1939).

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fraction of the thermal neutrons be captured by the element which is used for the purpose of slowing down, ~~then~~ we would have a chain reaction which may diverge for a sufficiently large mass of uranium.

This does not necessarily mean that a chain reaction can be maintained in a mixture of uranium oxide and water. In a homogeneous mixture of uranium oxide and water a considerable fraction of the neutrons is absorbed by uranium at resonance and it remains doubtful whether in such a mixture the number of neutrons produced may exceed the number of neutrons absorbed. (9) Fermi has investigated (June 1938) the question whether more favorable conditions can be obtained in mixtures of uranium oxide and water by keeping the uranium oxide and water in separate layers and found that a slight improvement can thus be obtained. ~~In spite of this,~~ But even so it was not possible to determine whether a chain ~~But even so, for the present the question whether a chain reaction can be obtained in a system composed of uranium and water is being left in abeyance.~~ ~~unanswered still open~~

But this improvement was not sufficient to determine whether a chain reaction can be obtained in a system composed of water and uranium oxide.

? [A recent experiment published by Halban, Joliot, Kowarsky and Perrin on a homogeneous U-H2O system (13) shows that such a system comes ~~close~~ (very close to be chain reacting) but still the question whether] ?

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