Anomalies in the Fermi Effect.

The present experiments on the Fermi Effect of indium show anomalies which ~~apparently compell us to chose between~~ ~~the~~ alternative ~~views. One of these alternatives views involves the assumption that a hitherto not observed heavy isotope of~~ the neutron is ejected from a stable isotope of ~~indium when indium is bombarded by neutrons. According to this view~~, the anomalous radio-active isotope of indium arises from one of the stable indium isotopes by a process in which the neutron is captured and ~~an~~ isotope of the neutron ~~of mass number 2 or 4 - or perhaps even more than 4 - is ejected.~~ There are arguments ~~against the assumption of the ejection of a double neutron, and the simplest~~ assumption ~~seems to be~~ that a tetra neutron is ejected from the more abundant stable isotope 115. ~~The present experiments will be discussed from the point of view of arguments~~ for and against this assumption.

~~The~~ Other ~~alternative view does not~~ involve the existence of a heavy neu~~tron isotope~~ at all, and it might be considered ~~by~~ some as equally probable, or even more ~~probable than the first alternative~~. While we ~~shall~~ emphasize the possibility of ~~this second~~ view, we will not discuss it in ~~such~~ detail as the ~~first alternative.~~ This unequal treatment is not due to a biased opinion in favour of one of ~~the two~~ views, and ~~seems to be~~ justified by the fact that the ~~first view~~ leads to a number of potentially possible experiments which may decide ~~in its favour, or may decide against it~~, whereas it seems to be difficult to think of experiments. ~~which lead to direct decisions on the second view.~~

ANOMALIES IN THE FERMI EFFECT

Amaldi, D'Agostino and Segrè have found [1] that neutrons which have been slowed down by paraffin wax induce in indium two radioactive half-life periods (16 sec. and 54 min.). T.A. Chalmers and I have subsequently reported [2] that indium can also be comparatively strongly activated with a third period of several hours if irradiated by neutrons from a radon alpha-particle beryllium source in the absence of hydrogen-containing substances, and we raised the question whether its existence can be satisfactorily explained without a new assumption. The two shorter half-life periods arise, to all appearances, from the two stable isotopes of indium, 113 and 115, by a process in which the neutron is captured and added to the indium nucleus (radiative capture) and can accordingly be attributed to two radioactive isotopes of indium - 114 and 116.

In the present experiments, the behaviour of the third period - the half-life of which I have now found to be 4½ h. - has been investigated, using various sources of neutrons.

Gamma rays from radium C liberate neutrons from beryllium as previously reported [3] and these photo-neutrons are efficient in activating elements which transmute into their own isotopes by adding a neutron to the nucleus (radiative capture). By irradiating indium for more than ~~twk~~ twelve hours with such photo-neutrons in the absence of hydrogen-containing substances, (the presence of which would unduly reinforce the 54 m. period) I obtained 5 minutes after irradiation activities up to about 150 kicks per minute on the Geiger Müller beta-ray counter, which decayed to less than 2 kicks per minute in eight hours. These kicks are due entirely to the 54 m. period, no trace being found of the 4½ h. period.

Using neutrons from radon alpha-particle beryllium and radon boron sources, I compared in both cases the initial intensity of the 4½ h.

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1) Amaldi, D'Agostino and Segrè. La Ricerca, Anno V. Vol.ii, n.910.
2) Szilard and Chalmers, Nature Vol. 135, p. 98, 1935.
3) Szilard and Chalmers, Nature Vol. 134, p.494, 1934.

Anomalies in the Fermi Effect.

The present experiments on the Fermi Effect of indium show anomalies which apparently compell us to chose between two alternative views. One of these alternativex views involves the assumption that a hitherto not observed heavy isotope of the neutron is ejected from a stable isotope of indium when indium is bombarded by neutrons. According to this view, the anamalous radio-active isotope of indium arises from one of the stable indium isotopes by a process in which the neutron is captured and an isotope of the neutron of mass number 2 or 4 - or perhaps even more than 4 - is ejected. There are arguments against the assumption of the ejection of a double neutron, and the simplest assumption seems to be that a tetra neutron is ejected from the more abundant stable isotope 115. The present experiments will be discussed from the point of view of arguments for and against this assumption.

The other alternative view does not involve the existence of a heavy neutron isotope at all, and it might be considered be some as equally probable, or even more probable than the first alternative. While we shall emphasize the possibility of this second view, we will not discuss it in such detail as the first alternative. This unequal treatment is not due to a biased opinion in favour of one of the two views, and seems to be justified by the fact that the first view leads to a number of potentially possible experiments which may decide in its favour, or may decide against it, whereas it seems to be difficult to think of experiments which lead to direct decisions on the second view.

2.) In order to obtain information on the vital points, a systematic investigation is necessary. Such an investigation would be also of scientific interest, and it appears that close co-operation with laboratories pertaining to the University of London would be possible. I think I could get hospitality and facilities for this work in one of these laboratories, and that I would be permitted to have a small staff working with me.

I understand that the only condition that would be imposed would be that the results should be published as soon as they are ascertained, but no objection would be raised against applying for patents before publication.

It would be desirable to have additional facilities of £2,000 available for the next two years, in order to speed up the work and ensure its continuity.

Note

by Kourtchatow, Myssowsky and Roussinow [8]. It is further conceivable that UX might perhaps emit spontaneously an isoptope of the neutron. Should UZ arise from UX through a beta transformation followed by a spontaneous ejection of an isotope of the neutron, it would not be an isotopic isobar of UX, and the one seemingly well-established case of isomerism would disappear.

One must, however, bear in mind that none of our arguments can be regarded as entirely conclusive until we succeed in understanding more fully the inter-action between the neutron and the nucleus. [illegible] It is conceivable, though there is no known precedent in the case of other elements, that the radio-active indium isotope (4 $\frac{1}{2}$ h.) is generated from the stable indium isotope 115, by radiative capture and that this process cannot be brought about by neutrons of a few hundred thousand volts, but can be brought about by neutrons of a million volts of energy. It is further conceivable, (though there is no [illegible] known precedent in the Fermi effect of other elements) that this radio-active indium isotope (4 $\frac{1}{2}$ h.) has the same mass number as another radio-active indium isotope (16 sec. or 54 ms.) If the radio-active indium isotope (4 $\frac{1}{2}$ h.) is considered to be exceptional in these two respects, no further [illegible] is needed from the point of view of the present observations.

In these circumstances and in view of the far-reaching implications of the ejection of a heavy neutron isotope, it is desirable that all inferences drawn from accumulated evidence should be corroborated by direct observation of the ejection of such a particle, ~~Fairly extensive attempts are now being made in this direction.~~ or alternatively that the ejection of such a particle should be ruled out. Fairly extensive attempts are now being made in this direction.

Clarendon Laboratory,
OXFORD.

(LEO SZILARD)

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8) Kourtchatow, Myssowsky and Roussinow

In these circumstances, one might be inclined to think that the radio-active indium isotope (4½ h.) is generated from one of the two stable indium isotopes by a process in which the neutron is captured and a heavier isotope o f the neutron - a particle not observed hitherto - is ejected. The capture of a neutron by the less abundant indium isotope 113 and the ejection of a neutron of a mass number 2 in the process would lead to a radio active indium isotope 112. The capture of a neutron by the more ab. ind. Is. 115 and the ej. of a n of mass n. 4 in the process, mentioned above, would also lead to a r. is. of ind. of m. n. 112.

There are, however, arguments against the assumption that the indium isotope 113 is involved. Wehave, therefore, rather to consider the possibility that a neutron iscaptured by the indium nucleus 115 and ejects a neutron isotope of mass number 4 (or perhaps even higher than 4). The ejection of such a tetra-neutron would lead to a radio-active isotope of indium of mass number 112. Though the existence of atetra neutron has not beeen assumed hitherto, the present experiments give sufficiently strong evidence to warrant further work along this line.

We can get a lower limit for the mass of the tetra neutron by considering two radio-active elements, of which the lighter one arises from the heavier one through one alpha and two beta transformations. If the mass of the tetra neutron were larger than the mass difference of these two radio-active elements, the heavier element would spontaneously have to eject a tetra neutron and thus transmute into the lighter element. A lower limit for the mass of the tetra neutron can thus be given fairly accurately from the mass of the alpha particle, and the energy liberated in the form of the kinetic energy of the ~~helium atom~~ alpha particle, and the maximum kinetic energies of the beta particles, and the gamma rays which are invloved in the radio.active transformation. From the application of this principle to the transformation

we obtain as a lower limit for the mass of the tetra neutron . If we use the average kinetic energy of the beta particles instead of the maximum kinetic energy, we obtain somewhat lower value for this lower limit. [W about

We cannot expect that a particle with such a small mass defect should be ejected by slow neutrons from many stable isotopes. Yet ~~it looks as if this was the case~~ there is some indication for the ejection of this particle in the case of Bromine. Koutchatow, Myssowsky and Roussinow have discovered that three radio-active isotopes of Bromine can be generated from bromine and all three products (half-live periods 18 m. 4 h. 36 h.) can be generated by slow neutrons. Bromine has an odd atomic number and its two stable isotopes have mass numbers 79 and 81. We cannot exclude with certainty the ~~view that~~ existence of a third isotope (Mass number 77 or 83), of a relative abundance of less than 1 %, ~~should exist and~~ which might strongly capture slow neutrons, but the existence of Se 77 and Kr 83 does not at any rate ~~favour this view~~ encourage the assumption of its existence. The mass numbers 79, 80, 81 and 82 are allotted to either a stable Bromine isotope or to one of the three radioactive isotopes. ~~Further~~ Therefore, if no third stable isotope of Bromine exists, we may either assume that two different radio-active bromine isotopes have the same mass number (isomerism) or alternatively we may take the view that a slow neutron is captured by the stable bromine isotope 81 and ejects a tetra neutron leading to radio-active bromine isotope 78.

The view that a slow neutron may eject a tetra neutron from the stable bromine isotope 81 yielding to a radio-active bromine isotope 78 may however, lead to certain difficulties. We can obtain an upper limit for the mass difference of the stable bromine isotope 81 and the radio-active bromine isotope 78 from the mass of the neutron (   ) and the estimated lower limit for the mass of the tetra-neutron (   ). We obtain as upper limit for this mass difference (to   ). On the other hand Aston gives for the mass difference of the two stable bromine isotope 81 and 79 the value of   . From this we obtain as an upper limit for the mass difference of the stable bromine isotope 79 and the radio-active bromine isotope 78 the value of   . A negative value for this mass difference could not be reconciled with the fact that bromine 79 is stable and does not spontaneously transmute into bromine 78 by emitting a neutron. In any case if a slow neutron can indeed eject a tetra-neutron from bromine 81 and produce the radio-active bromine isotope 78, we have to conclude that a few million electron volts energy are sufficient for removing a neutron from the stable bromine isotope 79, thereby producing the radio-active bromine isotope 78. It remains to be seen whether this is so. Attempts will in any case have to be made to produce the radio-active isotope 78 from bromine by means of gamma rays of a few million volts energy.

Very similar considerations would hold if a slow neutron could eject a double neutron from the lighter bromine isotope 79 leading to . The mass of the double neutron is certainly not much less than 2 otherwise H(2) would spontaneously emit β rays.

Another element which seems to deserve investigation is UX_1. UX_2 and UZ are supposed to be isotopic isobars, and this is one seemingly well-established case of isomerism. It is however conceivable that UX_1 emits spontaneously an isotope of the neutron. Should UZ arise from UX_1 through a Beta transformation followed by a spontaneous ejection of an isotope of the neutron, it would not be an isotopic isobar of UX_2, and no well established case of isomerism would remain. One must, however, bear in mind that none of the arguments put forward in favour of the view that a heavy isotope of the neutron is ejected from certain elements can be regarded as entirely conclusive until we succeed in understanding more fully the interaction between the neutron and the nucleus. Moreover these arguments were based on a great variety of observations, some our own and some by others, including observations reporting on the absence of certain effects. If some of these observations should be incorrect or incomplete, our arguements would have to be revised. But even if all the observations are correct, it remains still conceivable, though there is no known precedent in the case of other elements, that the radio-active indium isotope (4½ h.) is generated from the stable indium isotope 115 by radiative capture and that this process cannot be brought about by neutrons of a few hundred thousand volts, but can be brought about by neutrons of a million volts of energy. It is further conceivable (though there is no known precedent in the Fermi Effect of other elements) that that this radio-active isotope (4½ h.) has the same mass number an another radio-active isotope (16 sec. or 54 min.). If the radio-active indium isotope (4½ h.) is considered to be exceptional in these two respects, no further assumption is needed from the point of view of the present observations.

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However, as mentioned above, it is not likely that the less abundant indium isotope 113 should be involved at all.

However, we have arguments against the assumption that the indium isotope 113 is involved. We have therefore to consider the possibility that a neutron is captured by the indium nucleus 115 and ejects a neutron isotope of mass number 4 (or perhaps even higher than 4). The ejection of such a tetra neutron would lead to a radio-active isotope of indium of mass number 112. Though the existence of a tetra-neutron has not been assumed hitherto, the present experiments give sufficiently strong evidence to warrent further work along this line. It has to be mentioned in this connection that there is one seemingly well established case of isomerism; Ux and Uz are supposed to be isotopic isobars. One might think it conceivable that Ux perhaps emits spontaneously an isotope of the neutron. Should Uz arise from Ux through a Beta transformation followed by spontaneous ejection of an isotope of the neutron, it would not be an isotopic isobar of Ux, and no well established case of isomerism would remain. However, the view that Ux_1 spontaneously emits a tetra neutron leads to serious difficulties. According to this view, Uz would be an isobar of Io. Uz is an isotope of Pa, whereas Io is an isotope of Th. From the energies of the Beta rays of Ux_1 and Ux_2 and the alpha rays of U, we can see that the mass of Io would be much higher that the mass of Uz, and it is therefore difficult to see why Io should not emit Beta rays and trandmute spontaneously into Uz if Uz were an isobar of Io.

Expected

In the circumstances it appeara advisable to attempt a direct observation of the ejection of the heavy isotope of the neutron. Whereas the ejection of the tetra neutron by a slow neutron from a stable element must in any case be exceptional, conversely the disintegration of ~~thx~~ a stable nusleus by a tetra-neutron must be the rule rather than the exception. This is due to the small mass defect of the tetra-neutron. Attempts will be made to observe the emission of positive nuclii (protons, alpha-particles etc.) arising from the disintegration of certain elements which are being exposed to a radiation which is suspected to contain heavy neutrons. Attempts will also be made to observe the effect of such radiation on some elements with a view to detecting the presence of heavy neutrons by observing some anomalous radio-activity induced in these elements.

The ~~fact~~ possibility that a tetra-netron might easily eject a neutron from most of the elements, and might eject two neutrons from some of the elements deserves particular attention, since it might lead to chain reactions in which the initial number of neutrons and tetra-neutrons is multiplied by a very large factor.

~~xxxxxxxxxxxxxxxxxxxxxxxx~~ The tetra neutron has a very small mass defect, and if it penetrates into the nucleus there is a large excess of energy present. In such a case two neutrons may be ejected one after the other, rather than one very fast neutron. It seems to me that this view fits in well with general ideas which have recently been put forward in order to explain the selective absorbtion of slow neutrons, by N. Bohr on the one hand, and Breit snd Wigner on the other hand. ~~xxxxxxxxxxxxexplain~~

It is ~~however~~ quite conceivable that we may find mixtures of elements in which a neutron has a probability "a" liberating a tetra-neutron from one element and a tetra-neutron would liberate on the average ~~1/b~~ more than ~~one neutron~~ 1/a neutrons from the other element. These neutrons will again in their turn liberate tetra neutrons ~~with the probability a.~~ ~~If a/b is larger than a 1,~~ and we may have a chain reaction in which the number of initial neutrons may be multiplied by a very large factor, the value of which is determined by the geometrical conditions. ~~Such~~ Chain reactions [of this type] would lead to a practically unlimited supply of energy and of radio-active bodies (which could be used for storing energy.)

~~In view of~~ the ~~xxxxx potential possibilities of such chain reactions~~ It appears advisable to attempt a direct observation of the ejection of the heavy neutron isotope in order to obtain direct evidence for its existence, or, alternatively, in order to show [that] it is not ejected from certain elements either by slow or by fast neutrons. Such attempts are now under way.

SUMMARY

Dr. Szilard reports that the 4½ h. half-life period of radio-active indium cannot be excited by photo-neutrons from a radon beryllium source. From this fact and other observations with radon boron neutrons and radon alpha-particle beryllium neutrons which he reports one may infer that a heavy isotope of the neutron, the existence of which has hitherto not been assumed, is ejected from indium if bombarded by fast neutrons. The radio-active isotope of indium may arise from the stable isotope of indium 115 by a process in which the neutron is captured and a heavy isotope of the ~~xxxxx~~ neutron is ejected. This neutron isotope should have a mass number of at least 4. The simplest assumption is that its mass number is equal to 4 and that accordingly the mass number of the radio-active indium isotope is 112.

Political Powers which have an interest in maintaining peace are ahead of the others and make up their mind to police the rest of the world.

It may very well be that no heavy isotope of the neutron exists, and that the observed anomalies have some more or less straightforward explanation. However, until we can exclude the existence of such a neutron isotope with certainty, it is preferable to avoid publishing in Scientific periodicals remarks about heavy neutron isotopes and those anomalies which may indicate their existence.

Attempts will be made to observe the ejection of a heavy neutron isotope , and efforts will also be made to show that it does not occur. It is not possible to foresee how long it will take to settle these questions, but it is to be hoped that if we communicate results in this particular field privately to each other, and thus avoid too much overlapping of our work, progress ~~xxxxthx xxbjxxx~~ will be accelerated. As soon as there is a concensus of opinion to the effect that no heavy isotope of the neutron exists, such unusual forms of publication as the present communication will become superfluous.

~~Ixxhxxxdxbexgxxdx~~

I should be glad to keep you informed about experiments in this particular field which come to my knowledge should you care to let me know that you wish to receive such communications.

Anomalies in the Fermi Effect of indium reported in the enclosed communication raise the question of the existence of the heavy isotope of the neutron. It appears conceivable that these anomalies indicate the ejection of aneutron of mass number 4 by a neutron from indium. By no means do the present experiments however furnish conclusive proof of this and it may very well be that the reported anomalies will find an explanation in which no heavy isotope neutron is involved.

A few words must be stated for the communication of the results so far obtained privately rather than publishing them in one of the Scientific periodicals.

It seems to me that the question whether we can bring about nuclear chain reactions, and the question whether such a heavy isotope of the neutron exists are intimately connected with each other. It would seem that if a neutron of the mass number 4 exists, we have to envisage the possibility of such chain reactions; if no heavy neutron isotope exists, there is no possibility of such chain reactions within the framework of our present knowledge.

The liberation of nuclear energy and it storage in the form of radio-activity would bdcome possible on a large scale through nuclear chain reactions. We must, however, not be too optimistic as far as useful applications are concerned. Even if a heavy neutron is ejected, from certain elements, and if nuclear chain reactions may be brought about, the physiological action of gamma-rays emitted in such transmutation processes might prevent useful applications of importance for a long time to come.

On the other hand, we cannot disregard the fact that if nuclear chain reactions can be brought about, explosive bodies may be constructed having moderate weight, and a very formidable destructive action. The use of such explosive bodies by certain Political Powers would lead to catastrophies which might perhaps be prevented if those

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~~Ixxxxxxxxxxxxxxxx~~
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Since it may very well be that no heavy isotope of the neutron exists, there is no reason ~~for~~ for going into a detailed ~~of~~ examination of a hypothetical situation. However — —