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Anomalies in Radioactivity Induced by Neutrons

AMALDI, D'Agostino and Segrè[1] have found that neutrons which have been slowed down by paraffin wax induce in indium radioactivity decaying with two half-life periods (16 sec. and 54 min.). These half-life periods arise, to all appearances[2], 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 they are accordingly attributed to two radioactive isotopes of indium, 114 and 116. T. A. Chalmers and I have reported[3] that indium can also be activated with a third period of several hours by fast neutrons, and we raised the question whether this fact can be satisfactorily explained without a new assumption.

In the present experiments, the behaviour of this third period—the half-life of which I have now found to be $4\frac{1}{2}$ hr.—has been investigated, using various sources of neutrons. This period apparently belongs to a radioactive isotope of indium[1,2] and chemical separations carried out by F. M. Brewer of the old Chemistry Department, Oxford, have confirmed that it does not belong to radioactive isotopes of cadmium, silver or tin.

If this radioactive indium isotope arises through radiative capture from a stable indium isotope, slow neutrons would be expected to excite to some extent its $4\frac{1}{2}$ hr. period. In order to investigate this question, it is advisable to use photoneutrons from radium C–beryllium sources which have no energies above 0·7 m.e.v., and to avoid the use of hydrogen-containing substances, the presence of which would unduly reinforce the 54 min. period. I find when irradiating indium with such photoneutrons no trace of the $4\frac{1}{2}$ hr. period, though the irradiation is so intense in these experiments that the 54 min. period gives 1,250 impulses per min. on the beta-ray counter (background about 50).

This negative result is rather striking in view of the fact that faster neutrons from radon–α–beryllium sources excite the $4\frac{1}{2}$ hr. period at least as strongly as the 54 min. period. So far there is no known case of a radiative capture of the neutron which can be brought about by faster neutrons but cannot be brought about by slower neutrons, and it is therefore somewhat difficult to believe that the radioactive indium isotope of the $4\frac{1}{2}$ hr. period arises through direct capture of the neutron by one of the stable indium isotopes. Indium, which is of odd atomic number, has only two stable isotopes[4], and if three radioactive isotopes were produced by direct capture, two of these would be of identical mass number (isomerism).

Our present knowledge of nuclear structure may be, however, too incomplete to rule out with certainty isomerism and radiative capture in the case of the $4\frac{1}{2}$ hr. period. It seems, for example, somewhat difficult to understand at present why some very heavy elements, for example, bismuth, capture slow neutrons so very weakly. If we decide to rule out radiative capture and isomerism in the case of the $4\frac{1}{2}$ hr. period, we are forced to conclude that the radioactive indium isotope to which this period belongs is of lower mass number than the lighter stable indium isotope—113—and to consider the particular possibility that it is of mass number 112.

Such a radioactive isotope 112 might be produced by a non-capture process in which a fast neutron knocks out another neutron from the stable indium isotope 113. That such a non-capture process accounts for the $4\frac{1}{2}$ hr. period seems, however, improbable from the following experiments.

I find that neutrons from radon–boron sources excite the $4\frac{1}{2}$ hr. period of indium and the 2·4 hr. period of phosphorus much more strongly than the other periods investigated, which are known to require fast neutrons for their excitation, such as the 10 min. and 15 hr. periods of aluminium, the 2·3 min. period of silicon and the 2·3 min. period of phosphorus.

These observations indicate that the $4\frac{1}{2}$ hr. period of indium can be excited by moderately fast neutrons and are in keeping with Bjerge and Westcott's experiments[5], which showed that moderately fast neutrons arising from the D + D reaction can excite the 2·4 hr. period of phosphorus.

Through the co-operation of E. T. Booth and C. Hurst, who are operating—jointly with C. H. Collie—a high-voltage neutron source at about 230 kv., I was able to irradiate indium with neutrons from the D + D reaction. I find that such neutrons, which have an energy of about 2·5 m.e.v., strongly excite the $4\frac{1}{2}$ hr. period of indium, the intensity of the excitation being of the same order of magnitude as that of the 2·4 hr. period of phosphorus.

The binding energy of the neutron in stable elements of moderately high atomic number is believed to be mostly 8 m.e.v., and a neutron would require energies of this order in order to knock out another neutron from the nucleus of such elements. But even if the binding energy of the neutron were exceptionally small in the case of 113, the small relative abundance of this isotope—reported[4] to be less than $5\frac{1}{2}$ per cent—would still make it appear unlikely that neutrons should be able to produce from it the exceptionally strong $4\frac{1}{2}$ hr. period by such a non-capture process.

Therefore, if this period really belongs to an indium isotope of mass number 112 or less, we have to consider the possibility that this radioactive isotope is generated from a stable indium isotope by a process in which the neutron is captured, and a hitherto unknown heavy isotope of the neutron is ejected. The ejection of such a neutron isotope of mass number 4 from the more abundant indium isotope 115 by such a capture process would lead to indium 112. Similarly, if the less abundant indium isotope 113 were involved, the ejection of a neutron isotope of mass number 2 would equally lead to indium 112.

It is easy to show that such a tetra neutron—if it exists—must have a mass exceeding about 4·016, and accordingly it should reveal its presence by causing disintegrations in various elements. Considerations leading to similar conclusions would apply to such a double neutron. It should therefore be possible to find out whether or not such heavy neutron isotopes are ejected by neutrons from indium or bromine by a systematic search for the occurrence of such disintegrations in various elements. I am at present making such a search, though the elements investigated so far have not shown positive effects.

The three radioactive bromine isotopes generated in the experiments of Kourtchatow, Myssowsky and Roussinow[7] seem to represent another well-established case of anomaly.

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LEO SZILARD.

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SUMMARY

Dr. Leo Szilard reports ~~anomalous behaviour of the $4\frac{1}{2}$ hr. period of~~ anomalies in the ~~observations on~~ ~~transformation~~ of a radioactive indium isotope, for which there is no known precedent. The possibility is discussed that a hitherto unknown heavy isotope of the neutron ~~may~~ might perhaps be ejected by neutrons ~~of about 2·5 m.e.v. energy~~ from a stable isotope of indium. ~~It appears more likely that the mass number of such a neutron isotope, which might be involved, would be rather 4 than 2.~~ Reasons are given for expecting such a neutron isotope to cause—if ~~they~~ it exists—disintegrations in various elements, ~~and this ought to make it possible to find out whether they are ejected.~~ if it is really ejected from indium or bromine.

~~If such a neutron isotope is really involved its mass number ought to be expected to be of mass number 4 rather 4 than 2.~~ and thereby to reveal its presence..

~~radioactive bromine isotopes generated in the experi-~~ments of Kourtchatow, Myysowsky, and Roussinow[6] which ~~raise~~ a problem possibly similar to that of ~~indium~~. None of the discussed interpretations of our observations can thus be accepted without additional evidence, ~~and indium will be further investigated~~

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SUMMARY

Dr. Leo Szilard reports anomalies concerning the generation of a radioactive indium isotope having a half life period of 4½ hr. From the experimental evidence one might think that two anomalies, isomerism and a new anomalous type of radiative capture, occur in indium. Since each of these anomalies in itself—if it exists—~~must be~~ is a rare occurrence it is difficult to believe that they should both occur for the same element unless there is a special reason for their combined occurrence. Alternative interpretations of the observations are ~~investigated~~ discussed including the possibility that a hitherto unknown heavy isotope of the neutron may be ejected from indium by a neutron.

I am at present making such a search for which, through the courtesy of the Indium Corporation of America 650 gm of indium ~~[illegible]~~ are now available for such a search.

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These observations indicate that the $4\frac{1}{2}$ hr. period of indium can be excited by moderately fast neutrons and are in keeping with Bjerge and Westcott's experiments[5], which showed that moderately fast neutrons arising from the D + D reaction can excite the 2·4 hr. period of phosphorus.

Through the co-operation of E. T. Booth and C. Hurst, who are operating—jointly with C. H. Collie—a high-voltage neutron source at about 230 kv., I was able to irradiate indium with neutrons from the D + D reaction. I find that such neutrons, which have an energy of about 2·5 m.e.v., strongly excite the $4\frac{1}{2}$ hr. period of indium, the intensity of the excitation being of the same order of magnitude as that of the 2·4 hr. period of phosphorus.

The binding energy of the neutron in stable elements of moderately high atomic number is believed to be generally about 8 m.e.v., and a neutron would require energies of this order in order to knock out another neutron from the nucleus of such elements. The generation of the $4\frac{1}{2}$ hr. period by such a non-capture process from indium 113 would only be possible if the binding energy of the neutron in this isotope were of an unexpectedly low value of less than 2·5 m.e.v.

Therefore, if this period really belongs to an indium isotope of mass number 112 or less, we have also to consider the possibility that this radioactive isotope is generated from a stable indium isotope by a process in which the neutron is captured, and a hitherto unknown heavy isotope of the neutron is ejected. The ejection of such a neutron isotope of mass number 4 from the more abundant indium isotope 115 by such a capture process would lead to indium 112. Similarly, if the less abundant indium isotope 113 were involved, the ejection of a neutron isotope of mass number 2 would lead to indium 112.

It is easy to show that a tetra neutron—if it exists—must have a mass exceeding about 4·016, and accordingly it should reveal its presence by causing disintegrations in various elements. Considerations leading to similar conclusions would apply to a double neutron. It should therefore be possible to find out whether or not such heavy neutron isotopes are ejected by neutrons from indium (or bromine) by a systematic search for the occurrence of such disintegrations in various elements. I am at present making such a search, with 600 gms. of indium (and bromine).

An estimate of the mass of such a tetra neutron based on current ideas on the neutron-neutron interaction leads to a value which is so much in excess of the lower limit, stated above to be 4·016, that the ejection of such a tetra neutron from indium 115 by a 2·5 m.e.v. neutron would appear to be impossible. That the ejection of a double neutron from indium 113 should account for the generation of the exceptionally strong $4\frac{1}{2}$ hr. period would seem surprising since the relative abundance[4] of this isotope is less than $5\frac{1}{2}$ per cent, but cannot be ruled out on this ground. Additional evidence is thus needed in order to decide between "anomalous capture" and the other discussed interpretations.

LEO SZILARD.

The Clarendon Laboratory,
University Museum,
Oxford.
Nov. 5.

[1] Amaldi, D'Agostino and Segrè, *Ric. Sci.* (v), **2**, No. 9–10.
[2] Amaldi, D'Agostino, Fermi, Pontecorvo, Rasetti and Segrè, *Proc. Roy. Soc.*, A, **149**, 522 (1935).
[3] Szilard and Chalmers, NATURE, **135**, 493 (1935).
[4] Wehrli, *Helv. Phys. Acta*, **7**, 611 (1934). Aston, *Proc. Roy. Soc.*, A, **149**, 403 (1935). Blewett, *Phys. Rev.*, **49**, 778 (1936).
[5] Bjerge and Westcott, NATURE, **134**, 177 (1934).

SUMMARY

Dr. Leo Szilard reports anomalies concerning the generation of a radioactive indium isotope having a half life period of $4\frac{1}{2}$ hr. From the experimental evidence one might think that two anomalies, isomerism and a new anomalous type of radiative capture, occur in indium. Since each of these anomalies in itself—if it exists—must be a rare occurrence it is difficult to believe that they should both occur for the same element unless there is a special reason for their combined occurrence. Alternative interpretations of the observations are investigated including the possibility that a hitherto unknown heavy isotope of the neutron may be ejected from indium by a neutron.

Unpublished paper

ANOMALIES IN RADIOACTIVITY INDUCED BY NEUTRONS

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Anomalies in Radioactivity Induced by Neutrons

AMALDI, D'Agostino and Segrè[1] have found that neutrons slowed down by paraffin wax induce in indium radioactivity decaying with two half-life periods (16 sec. and 54 min.) These half-life periods arise, to all appearances[2], 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 accordingly they have been attributed to two radioactive isotopes of indium, 114 and 116. T. A. Chalmers and I have reported that indium can also be activated with a third period of several hours by fast neutrons, and we raised the question whether this fact can be satisfactorily explained without a new assumption.[3]

In the present experiments, the behaviour of this third period - the half-life of which I have now found to be $4\frac{1}{2}$ hr. - has been investigated, using various sources of neutrons. This period apparently belongs to a radioactive isotope of indium[2]; F. M. Brewer of the Old Chemistry Department, Oxford, and I have confirmed that it does not belong to radioactive isotopes of cadmium, silver or tin.

If this radioactive indium isotope arises through radiative capture from a stable indium isotope, slow neutrons may be expected to excite to some extent its $4\frac{1}{2}$ hr. period. In order to investigate this question, it is advisable to use photoneutrons from radium-beryllium sources which have no energies above 0·7 m.e.v., and to avoid the use of hydrogen-containing substances, the presence of which would unduly reinforce the 54 min. period.

I find when irradiating indium with such photo-neutrons no trace of the $4\frac{1}{2}$ hr. period, though the irradiation is so intense in these experiments that the 54 min. period gives 1,250 impulses per min. on the beta-ray counter (background about 50).

This negative result is rather striking in view of the fact that fact neutrons from radon-α-beryllium sources excite the $4\frac{1}{2}$ hr. period at least as strongly as the 54 min. period. So far there is no known case of a radiative capture of the neutron which can be brought about by faster neutrons but cannot be brought about by slower neutrons. If the radioactive indium isotope of the $4\frac{1}{2}$ hr. period arose through direct capture of the neutron by one of the stable indium isotopes this capture would be anomalous. Moreover, indium has only two stable isotopes[4], and if three radio-active isotopes were produced by direct capture, two of these would be of identical mass number (isomerism).

Our present knowledge of nuclear structure does not allow to rule out isomerism and anomalous capture in the case of the $4\frac{1}{2}$ hr. period. It is, however, very improbable that two such anomalies as isomerism and a new type of radiative capture (requiring fast neutrons) should both occur in the same element unless there is special reason for their combined occurrence, because each of these two anomalies - if it exists - is rare. Since for the time being no such reason is apparent, we have to investigate other alternative interpretations of our observations. If we decide to rule out radiative capture and isomerism in the case of the $4\frac{1}{2}$ hr. period, we are forced to conclude that the radioactive indium isotope to which this period belongs is of lower mass number than the lighter stable indium isotope - 113 - and to consider the particular possibility that it is of mass number 112.

Such a radioactive isotope 112 might be produced by a non-capture process in which a fast neutron knocks out another neutron from the stable indium isotope 113. That such a non-capture process accounts for the $4\frac{1}{2}$ hr. period seems, however, improbable from the following experiments.

I find that neutrons from radon-boron sources excite the $4\frac{1}{2}$ hr. period of indium and the 2·4 hr. period of phosphorus much more strongly than those other investigated periods which are known to require fast neutrons for their excitation, such as the 10 min. and 15 hr. periods of aluminium, the 2·3 min. period of silicon and the 2·3 min. period of phosphorus.

These observations indicate that the $4\frac{1}{2}$ hr. period of indium can be excited by moderately fast neutrons and are in keeping with Bjerge and Westcott's experiments,[5] which showed that moderately fast neutrons arising from the D + D reaction can excite the 2·4 hr. period of phosphorus.

Through the co-operation of E. T. Booth and C. Hurst, who are operating - jointly with C. H. Collie - a high-voltage neutron source at about 230 kv., I was able to irradiate indium with neutrons from the D + D reaction. I find that such neutrons, which have an energy of about 2·5 m.e.v., strongly excite the $4\frac{1}{2}$ hr. period of indium, the intensity of the excitation being of the same order of magnitude as that of the 2·4 hr. period of phosphorus.

The binding energy of the neutron in stable elements of moderately high atomic number is believed to be generally about 8 m.e.v., and a neutron would require energies of this order in order to knock out another neutron from the nucleus of such elements. The generation of the $4\frac{1}{2}$ hr. period by such a noncapture process from indium 113 would only be possible if the binding energy of the neutron in this isotope were of an unexpectedly low value less than 2•5 m.e.v.

Therefore, if this period really belongs to an indium isotope of mass number 112 or less, we have also to consider the possibility that this radioactive isotope is generated from a stable indium isotope by a process in which the neutron is captured, and a hitherto unknown heavy isotope of the neutron is ejected. The ejection of such a neutron isotope of mass number 4 from the more abundant indium isotope 115 by such a capture process would lead to indium 112. Similarly, if the less abundant indium isotope 113 were involved, the ejection of a neutron isotope of mass number 2 would lead to indium 112.

It is easy to show that a tetra neutron - if it exists - must have a mass exceeding about 4•016, and accordingly it should reveal its presence by causing disintegrations in various elements. Considerations leading to similar conclusions would apply to a double neutron. It should therefore be possible to find out whether or not such heavy neutron isotopes are ejected by neutrons from indium (or bromine) by a systematic search for the occurrence of such disintegrations in various elements. I am at present making such a search with 60 grs. of indium (and bromine).

An estimate of the mass of such a tetra neutron based on current ideas on the neutron-neutron interaction leads to a value which is so much in excess of the lower limit, stated above to be 4·016, that the ejection of such a tetra neutron from indium 115 by a 2·5 m.e.v. neutron would appear to be impossible. That the ejection of a double neutron from indium 113 should account for the generation of the exceptionally strong $4\frac{1}{2}$ hr. period would seem surprising since the relative abundance[4] of this isotope is less than $5\frac{1}{2}$ per cent, but cannot be ruled out on this ground. Additional evidence is thus needed in order to decide between "anomolous capture" and the other discussed interpretations.

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1. Amaldi, D'Agostino and Segrè, *Ric. Sci.* (v), 2, No.9-10.

2. Amaldi, D'Agostino, Fermi, Pontecorvo, Rasetti and Segrè, *Proc. Roy. Soc.*, A, 149, 522 (1935).

3. Szilard and Chalmers, NATURE, 135, 493 (1935).

4. Wehrli, *Helv. Phys. Acta*, 7, 611 (1934). Aston, *Proc. Roy. Soc.*, A, 149, 403 (1935). Blewett, *Phys. Rev.*, 49, 778 (1936).

5. Bjerge and Westcott, NATURE, 134, 177 (1934).

The Academic Copying Office, 21 The Turl, Oxford.

Letter to " NATURE ".

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 radio-active 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 radio-active 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 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.

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1) Amaldi, D'Agostino and Segrè. La Ricerca, Anno V. Vol.11, n.910.
2) Szilard and Chalmers, Nature Vol. 135, p.98, 1935.
3) Szilard and Chalmers, Nature Vol. 134, p.494, 1934.

Using neutrons from radon alpha-particle beryllium and radon boron sources, I compared in both cases the initial intensity of the $4\frac{1}{2}$ h. period with that of the 54 m. period and found that the intensity of the $4\frac{1}{2}$ h. period is about equal to or larger than the intensity of the 54 m. period.

Using neutrons from a radon boron source, I compared the intensity of the $4\frac{1}{2}$ h. period of indium with that of the 10 m. and 15 h. period of aluminium, the 2.3 m. period of silicon and the 2.3 m. period of phosphorus. I find that the $4\frac{1}{2}$ h. period of indium is more intense than any of these other periods and at least   times as intense as the 2.3 m. period of Si. and the 15 h. period of Al. (Incidentally it is also more intense than the 25 m. period of iodine). The 2.4 h. period of phosphorus is about twice as intense as the $4\frac{1}{2}$ h. period of indium.

In the case of the $4\frac{1}{2}$ h. period of indium we know from the chemical evidence[4] that we have to deal with a radio-active isotope of indium. The fact, however, that photo-neutrons do not excite this period in the present experiments rather indicates that ~~our~~ this radio-active indium isotope is not generated from one of the stable indium isotopes by a process in which the neutron is simply added to the nucleus (radiative capture). Therefore ~~our~~ this radio-active indium isotope has presumably a smaller mass number than the stable indium isotope from which it is generated.

The present observations on radon boron neutrons, on the other hand, strongly discourage the assumption that ~~our~~ this radio-active indium isotope is produced by fast neutrons by a "non-capture" process in which a neutron is knocked out from one of the stable indium isotopes. Amaldi, D'Agostino, Fermi, Pontecorvo and Segrè[5] already have put forward the view that radon boron sources emit much fewer neutrons of very high energies than radon alpha-particle beryllium sources. The present experiments support this view by showing that the 2.4 h. period

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4)

5) Amaldi, D'Agostino, Fermi, Pontecorvo and Segrè

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of phosphorus (which according to Bjerge and Westcott[6] can be excited by neutrons of less than 3 MEV energy) is more than times as strongly excited as the 2.3 m. period of Si. and the 15 h. period of Al. It is unlikely that such moderately fast neutrons should be able to excite very strongly the 4½ h. period of indium if this period were due to a "non-capture" process, and the fact that we find this period to be the strongest next to the 2.4 h. period of P. rules out such an assumption. This fact makes it also appear improbable that the radio-active indium isotope, to which this period belongs, is generated in any other way from the less abundant stable indium isotope 113, the relative abundance of which[7] is less than 5½%.

The fact that the mass numbers 113, 114, 115, 116 are allotted to indium isotopes, which are either stable or have the half-life periods of 16 sec. and 54 m. respectively, also strongly supports our inferences if we rule out the possibility of isotopic isobars (isomerism).

While one must 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, tentative conclusions may be drawn from the accumulated evidence. In the circumstances one ~~should be~~ may be inclined to think that ~~our~~ the radio-active indium isotope is generated from the stable indium isotope 115 by a process in which the neutron is captured and a heavier isotope of the neutron - a particle not observed hitherto - is ejected. For instance if a neutron is captured by the indium nucleus 115 and ejects a particle of ~~the~~ mass number 4, and the charge 0, a radio-active isotope of indium of ~~the~~ mass number 112 may arise.

6) Bjerge & Westcott "Nature"

7) Aston Proc. Roy. Soc.

The existence of such an isotope of the neutron - a tetra-neutron - has not been assumed hitherto. The present experiments, however, give sufficiently strong evidence in its favour to encourage further work along this line.

Some other elements are suspect of emitting such an isotope of the neutron when bombarded by fast or slow neutrons and one element might be suspected of spontaneously emitting an isotope of the neutron. The ejection of a tetra-neutron from the heavier of the two stable bromine isotopes by a slow neutron might for instance explain the generation of three radio-active isotopes of bromine, which has recently been discovered by Kourtchatow, Myssowsky and Roussinow.[8] If UZ should arise from UK, through a beta transformation followed by a spontaneous ejection of an isotope of the neutron, it would not be an isotopic isobar of UK_2 and the one seemingly well-established case of isomerism would disappear.

Attempts are now being made to observe the ejection of an isotope of the neutron from various elements, the possibility of which may be inferred from the present observations.

Clarendon Laboratory,
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Leo Szilard.

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8) Kourtchatow, Myssowsky and Roussinow

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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.

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

1) Amaldi, D'Agostino and Segrè. La Ricerca, Anno V. Vol.ii, n.910.
2) Szilard and Chalmers, Nature Vol. 135, p. 98, 1935.
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Using neutrons from a radon boron source, I compared the intensity of the 4½ h. period of indium with that of the 10 m. and 15 h. period of aluminium, the 2.3 m. period of silicon and the 2.3 m. period of phosphorus. I find that the 4½ h. period of indium is more intense than any of these other periods and at least times as intense as the 2.3 m. period of Si. and the 15 h. period of Al. (Incidentally it is also more intense tham the 25 m. period of iodine). The 2.4 h. period of phosphorus is about twice as intense as the 4½ h. period of indium.

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4) Amaldi, D'Agostino, Fermi, Pontecorvo, Rasetti and Segrè, Proc. Roy.Soc.
5) Amaldi, D'Agostino, Fermi, Pontecorvo and Segrè
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6) Bjerge and Westcott "Nature"

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Two radio-active products arising from indium (54 m 4 1/2 h.) have been chemically identified as radio-active isotopes of indium ~~and~~ there is indirect evidence in favour of the view that the 16 sec. product is also a radio-active isotope of indium. ~~This is indicated by the experiment of~~ Chadwick and Goldhaber ~~who~~ searched for an alpha particle emission from indium, while the indium was being bombarded with slow neutrons ~~with negative results.~~ ~~The ejection of~~ a proton by a slow neutron from indium ~~can be ruled out on theoretical grounds.~~ In these circumstances it appears likely that the 16 sec. product arises by radiative capture and belongs to a radio.active isotope of indium.

The fact that the mass mumbers 113, 114, 115, 116 are allotted to indium isotope which are either stable or have the half-life periods of 16 sec. and 54 m. respectively, also strongly supports our inferences if we rule out the possibility of isotopic isobars (isomerism).

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Some other elements might be expected to emit a heavy isotope of the neutron when bombarded by fast or slow neutrons. The ejection of a tetra-neutron from the heavier of the two stable bromine isotopes by a slow neutron might for instance explain the generation of three radio-active isotopes of bromine, which has recently been discovered

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Expose

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 lèberated in the form of the kinetic energy of the helium atom, 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.

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 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 atomic number and its two stable isotopes have mass numbers 79 and 81. We cannot exclude with certainty the view that a third isotope (Mass nümber 77 or 83), of a relative abundance of less than 1 %, should exist and strongly capture slow neutrons, but the existence of Se 77 and Kr 83 does not favour this view. The mass numbers 79, 80, 81 and 82 are allotted to either a stable Bromine isotope or to one of the three. Further, 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 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.