From F 53

Dated Oct 18, 1938

IN THE UNITED STATES PATENT OFFICE

In re application of	)	
LEO SZILARD	)	
Serial No. 10,500	)	APPARATUS FOR NUCLEAR TRANSMUTATION
Filed March 11, 1935	)	
Div. 56 - Room 4725	)	

AFFIDAVIT OF LEO SZILARD

STATE OF NEW YORK)
) ss:
COUNTY OF NEW YORK)

LEO SZILARD, being duly sworn, deposes and says:

I am at present on leave of absence from the Clarendon Laboratory, Oxford, where I have been engaged in research work in the field of nuclear physics including induced radio-activity since 1935. Immediately preceding that in 1934 I was working in the same field as a guest of the Physics Department of St. Bartholomew's Hospital, London, and also as a Research Associate of New York University, New York City. I am a Doctor of Philosophy in Physics of the University of Berlin. I was connected for a number of years as Privatdozent for Physics with the teaching staff of that university.

When I filed the British provisional application on March 12, 1934, it was known through the work of M. and Mme. Joliot that radio-active elements can be produced from natural elements by bombarding the natural element with alpha particles emitted from polonium - one of the natural radio-active elements. Also I should mention that the following passage is contained in an article which F. Joliot and I. Curie published in "Nature" for February 10, 1934:

"... These elements and similar ones may possibly be formed in different nuclear reactions with other bombarding particles: protons, deutrons, neutrons."

Although the possibility that some of the particles other than alpha particles might (or might not) produce radio-activity was thus thrown open for discussion, the fact that neutrons can induce radio-activity in a natural element was not publicly known until Professor Fermi announced his discovery in a letter dated March 25, 1934 published in Ricerca Scientifica, Vol. 1, p. 283. Fermi produced the neutrons with which he demonstrated his discovery by bombarding beryllium with alpha particles from a radon source, one of the natural radio-active elements. Fermi's discovery was considered to be of great scientific importance.

Any scientific worker in any of the scientific laboratories which have access to natural radio-active elements could have made this discovery and demonstrated it to others in a few minutes if he had known that neutrons induce radio-activity and had realized that they are so efficient in inducing radio-activity that even the weak neutron sources which can be maintained by bombarding beryllium with the alpha particle of a natural radio-active element are sufficiently strong to give an effect easily observable in the laboratory. It may be that radio-activity induced by neutrons would have been discovered long before Fermi if only physicists had realized the efficiency of neutrons for this purpose. If a physicist did not foresee that this process will be much more efficient than the production of radio-activity by alpha particles previously demonstrated by Joliot, he would not have attempted to make the experiment with neutrons even if he had thought that neutrons might possibly produce radio-activity.

In view of the fact that neutron sources which are maintained by bombarding beryllium with alpha particles from a natural radio-active element emit only very few neutrons in comparison with the number of alpha particles used, and since the activity is just nicely observable in the laboratory if these alpha particles directly produce radio-activity by the method of Joliot, one might think that the radio-activity produced by so much fewer neutrons will not be noticeable at all. Therefore it was an essential step to realize that neutrons when properly applied are much more effective than alpha particles in producing radio-activity, so that their great effectiveness can be made to compensate or more than compensate for their relative scarcity.

The reason for the greater effectiveness of the neutrons lies in the following: If a charged particle, like an alpha particle, is used for bombarding a target in order to produce radio-active elements from the natural elements contained in the target, only a very thin sheet of the target will be reached by the alpha particles, for these particles are stopped in a thin layer which corresponds to the range of these particles. The reason for the small range is the fact that the alpha particle ionizes the substance through which it passes and rapidly loses its energy. Neutrons, however, do not ionize and suffer no energy losses except through comparatively rare nuclear collisions. This is the reason why neutrons have a large mean free path, long range and are generally known to be a more penetrating radiation. By exposing the element to be made radio-active in a sheet which is sufficiently thick, advantage is taken of the fact that neutrons do not suffer any losses through ionization and therefore are not stopped by a thin layer. The production of radio-activity by neutrons can thus be made an efficient process.

As pointed out in my patent application, in order to obtain good efficiency, the natural element should be contained in a layer which surrounds the source of neutrons and the thickness of the layer should be sufficient to take advantage of the great penetrating power of the neutrons. Also, industrial significance is only obtained if the neutrons are produced by electrical discharge using electrical energy and thereby converting electrical energy into gradually released nuclear energy. As to the thickness of the layer which is required, it is obvious from my patent specification that since the neutrons are a penetrating radiation, the efficiency will increase with increasing thickness of the layer. At the time ~~that~~ when I filed my provisional application on March 12, 1934, the order of magnitude of the mean free path of the neutrons was already known from experiments in which the neutrons are scattered and in which the scattering cross-section of the elements is determined. It is obvious that if the thickness of the layer is small compared with the mean free path only few neutrons will collide with a nucleus within the layer and the efficiency will be small.

It was known before my filing date, March 12, 1934, that neutrons can produce nuclear disintegrations, that is that neutrons can disrupt a nucleus. In experiments in which this has been demonstrated gases have been bombarded by neutrons in the Wilson cloud chamber, and the disruption of individual nuclei was observed rather than any properties of the disintegration products. It might be that accidentally radio-active elements were produced in these experiments from natural elements by neutron bombardment, but, if so, they necessarily escaped detention, the experimental setup not being devised for the purpose of their detection. The neutrons were produced by bombarding beryllium with alpha particles for a natural radio-active element and not by means of electrical power, and the requirements for an efficient and industrially significant production of radio-active elements by neutron bombardment were not met in these experiments. However obvious these requirements which are set out in my patent specification may be considered to be if one knows that neutrons do produce radio-active elements from natural elements, it is unlikely that these requirements were met without this knowledge in these earlier experiments which were directed to observation of individual disintegration processes and not towards the observation of artificial radio-activity. There is no disclosure in any of the publications that they were met.

As to the question whether every natural element can be transformed by neutrons into a radio-active element, I wish to state the following: If a sample of a natural element is used in the form in which it has chemically been isolated from some compound found in nature, this sample is composed of a number of isotopes of different mass number but the same atomic charge. If such a sample is bombarded with neutrons on the basis of at present generally accepted views, the following argument can be put forward in favor of the view that a radio-active element is produced from it which is isotopic with the natural element. It can be argued that, according to these views, such a sample contains as a rule all stable isotopes of the elements. According to this view, isotopes of a given element which have a larger mass number than the heaviest isotope in the sample are unstable, i.e. radio-active, and that instability is the reason for their absence. (It is equally true that the isotopes of smaller mass number than the lightest isotope in the sample are unstable and therefore radio-active, but these isotopes are not produced by slow neutrons such as neutrons produced from an X-ray-beryllium source. Neutrons from such a source produce radio-activity by neutron capture.) If this view is correct, then any natural element ought to become radio-active through capturing a neutron. This can be concluded in the following way: Let us consider the heaviest isotope of a given element. If that isotope captures a neutron a new element is produced which is isotopic with the element from which it was produced but has a mass number larger than the mass number of thehheaviest isotope of the element. Accordingly the new element cannot be a stable isotope of the old element but must be an unstable and therefore radio-active isotope. I should add that the half life time of such a radio-active isotope might be large, in which case it might escape detection if looked for after a short neutron bombardment. While these theoretical deductions may not be sufficiently well founded for us to ~~conclude~~ exclude with certainty that certain elements for reasons unknown might refuse to capture a neutron, it is a well-established experimental fact that many elements capture neutrons and that, if an element is irradiated by neutrons, the production of a radio-active element is the rule rather than the exception.

Subscribed and sworn to before me
this 18th day of October, 1938.

Madeline Sigward
Notary Public

NOTARY PUBLIC, Queens County
Queens County Clerk's No. 1873
Queens County Register's No. 1485
Certificate filed in New York County
New York Co. Clerk's No. 376
New York Co. Register's No. 0 S 263
Commission expires March 30, 1940

from F-53

IN THE UNITED STATES PATENT OFFICE

Applicant: LEO SZILARD.	)	
Serial No: 10,500	)	Apparatus for Nuclear
Filed: March 11, 1935	)	Transmutation.
Div. 56. Room 4725.	)	

Hon. Commissioner of Patents,
Washington, D.C.

Sir,

In response to the Official Action of 28th March 1936, please amend this Application by cancelling the whole of the descriptive portion of the Specification and all the claims and substitute the following description and new claims 24 to 51.

This invention concerns methods and apparatus for the generation of radio-active bodies.

According to my invention radio-active elements may be produced from light and heavy elements when such elements are subjected to the effect of a neutron bombardment. Such a neutron bombardment may be effected by causing accelerated heavy hydrogen (diplogen) atoms or nuclei to collide with diplogen or other light elements.

Other features of the invention will appear in the detailed description referring to the drawings which now follows, and will be more particularly pointed out in the claims.

In the drawings,

Figure 1 represents a sectional elevation of an apparatus for carrying out the invention,

Figure 2 shows a more constructional lay-out of the apparatus of Figure 1,

Figure 3 indicates diagrammatically the circuit arrangement of modified apparatus for the performance of the invention,

Figure 4 is a more detailed view corresponding to Figure 3,

Figure 5 shows the circuit arrangements for further modified apparatus and,

Figure 6 is a sectional view of apparatus intended to co-operate with that shown in Figure 5.

Referring first to Figure 1 of the drawings, 11 is an electrical discharge tube adapted to project a beam 12 of fast diplogen ions. The tube 11 is filled with diplogen and an anode A and cathode B are provided for connection to a source of high voltage. The diplogen ions are thus projected at high speed and pass through the cathode B. The ions fall on a substance 13 in a sealed container 13A. The substance 13 consists, for instance, of gaseous diplogen, or a diplogen compound or lithium. The collision of the fast diplogen ions with the substance 13 causes transmutation, i.e. a nuclear reaction of the diplogen ion with an atom of the target. The substance 13 is surrounded by a thick layer 14 containing the element or substance which it is desired to transmute into a radio-active element or substance. In order to have a high efficiency, the thickness of the layer 14 has to be sufficiently great, compared with the mean free path of the neutron, to prevent escape of any of the neutrons.

Figure 2 shows in more detail the electrical discharge tube 11 referred to in Figure 1. The tube essentially consists of a main portion 16 serving to accelerate the diplogen ions and an auxiliary tube 11^T for initiating the flow. 11A is the anode and 15 the cathode of the auxiliary tube, diplogen being admitted thereto through the inlet 13B and being pumped away through the outlet 14A. The flow initiated by the auxiliary tube is accelerated by passage through the main tube 16 which is maintained exhausted by suction outlets 14^1 and 14^2, and which has a high potential gradient, there being a million volt potential difference between the ends of the tube. The accelerated diplogen ions emerge through the neck 14^3 of the tube 16 and collide with the substance 13 as described with reference to Figure 1 of the drawings.

If the substance 13 is a light element for instance diplogen, or lithium, then the bombardment by the accelerated diplogen ions results in emission of uncharged particles of mass of the order of magnitude of the mass of a proton. Such uncharged nuclei i.e. neutrons, penetrate even substances containing the heavier elements without ionisation losses, and will cause the formation of radio-active substances in the layer 14 exposed to them. It is to be observed that by the method so far described, the ionisation losses on collision of the diplogen nuclei with light nuclei are comparatively small due to the orbited electrons of light elements and also that the substance to be made radio-active is irradiated with neutrons i.e. uncharged nuclei, which pass through even heavy elements without ionising them. The substance 14 exposed for treatment by the neutron radiation may be in the form of an organic material for the purpose of carrying out separation of the generated radio-active part, as described more fully hereinafter.

The method for the production of neutrons just described consists essentially of discharging particles through matter which is at rest. A diplon (a diplogen nucleus) shot into diplogen at rest will in a large proportion of cases lose its energy by ionising the diplogen and cause no transmutation. In the following I shall describe a method by which a great concentration of energy is produced in a body of diplogen or other light element or elements, the energy concentration being such as to cause the nuclei in the body of substance to collide with one another. Under these conditions, which need be maintained only momentarily, neutron radiation is produced and can be used for the treatment of an element to render it radio-active.

Apparatus for this purpose is illustrated in Figure 3, 52 being an electric condenser which is fed through inductive chokes 53 and 54, from a high potential supply. One side of the condenser is connected to a spark gap device 51 which is in turn connected with the cathode 42 of a discharge tube 41. In Figure 4 this discharge tube 41 is shown on a larger scale, the electrical arrangement for operating the tube being the same as shown in Figure 3. The discharge tube is formed as a cathode ray tube, there being the cathode 42 and an anode connection 42A, to allow the spherical shell 42B onto which the tube 41 connects, to act as the anode. The end of the tube 41 is sealed off at 42C by means of a thin metallic window. At the centre of the spherical shell 42B is a spherical container 44 filled with diplogen. As indicated in the drawings more than one of the cathode ray tubes 41 may be mounted radially upon the spherical shell 42B, so that the emergent corpuscular rays from the said cathode ray tubes focus upon the container 44. In operation a high potential is supplied to the condenser 52 through the chokes 53 and 54, and when such potential reaches a predetermined critical value the condenser discharges and causes a spark to pass between the poles of the spark gap device 51. The cathode ray tube or tubes 41 are thereby energized and corpuscular cathode rays are produced. These rays serve as heating rays and cause the diplogen contained in the container 44 to have its energy contents raised up to a very high value for a short period. Such energy concentration produces interaction of the diplogen nuclei with the consequent formation of neutron rays.

Cathode rays have been suggested to perform the heating or energy concentrating action referred to above, but it will be understood that protons or heavier ions might instead be used. Furthermore, the container 44 might be filled with diplogen alone or lithium hydride, or other compounds of hydrogen and lithium, or other compounds of hydrogen or diplogen with a third light element. The container 44 encloses the transmutation space from which the neutron rays emerge and by surrounding the space with substances to be treated for the purposes of making them radio-active, such substances may be bombarded with neutrons in the same way as was described with reference to Figures 1 and 2 of the drawings.

Neutron radiation may also be produced by the action of X-rays upon an element having a dissociable neutron at the prevailing voltage, and apparatus for carrying out this process will now be described with reference to Figure 5 of the drawings.

In Figure 5, 1 is the primary of a transformer, the secondary 2 of which is connected to the junctions 3 and 4. The junction 3 is connected to the cathode 8 of the rectifier tube 5 and to the anode 7 of the rectifier tube 6. The junction 4 is connected to the cathode 9 of the rectifier tube 10 and to the anode 11 of the rectifier tube 12. The cathodes 13 and 14 are connected to each other and to earth. The anodes 15 and 16 are connected at 17, and from this point are connected to the pole 18 of the impulse generator 20, the pole 19 of which is connected to earth. The impulse generator 20 is built of condensers 21, resistances 22 and spark-gap devices 23.

The impulse generator and rectifying unit shortly described above, are known components adapted to give an extremely high voltage for a fraction of a second. With such a system voltages up to 3 million volts have been obtained. The negative side of the impulse generator is connected to a spark gap device 25, which in turn is connected with the cathode 26 of the discharge tube 24. The latter is built up from rings 24A of which only a few are shown in the drawing. It will, however, be understood that the rings are continuous to enclose a space which is exhausted through the outlet 24B. The anode 27 of the tube is connected to earth and is formed by a metallic window. A body of material 28 is arranged at the external side of the window 27.

When the impulse generator operates to produce discharge between the cathode 26 and anode 27 of the tube 24, fast electrons penetrate the anode 27 and impinge upon the body 28. The latter when formed of Bi or Pb or some other heavy element, acts as an anti-cathode and hard X-rays are produced.

In Figure 6 of the drawings there is shown the lower portion of the discharge tube 24 with a device therebeneath for utilising the hard X-rays capable of being produced with the aid of the fast electrons emerging through the anode 27 of the tube 24. The device consists of a block 34 of the element which is to be made radio-active, a block 32 of an element with a dissociable neutron, being located therein. An aperture is formed in both the blocks 32 and 34 to allow entry of the rays from the tube 24 above. The blocks 32 and 34 are also arranged to accommodate a wheel 30 and axle 35. The wheel 30 at its periphery carries a covering of tungsten or lead 31. The covering 31 acts as an anti-cathode and is cooled with water introduced along the bearing for the axle 35. The block 34 may be in the form of a cube having a length of side of 50 cms., whilst the block 32 can also be of cube form with a side of 25 cms. For the sake of example the block 34 may be formed of iodine or arsenic or other material which lends itself to being made radio-active. The block 32 may be of metallic beryllium. In order that an isotopic separation as described hereinafter may be performed after irradiation the material of the block 34 may be in the form of an organic compound. A voltage of 3 million volts may be used for the discharge tube and in operation the wheel 30 is rotated so that electrons passing through the anode 27 of the tube 24 hit the rotating anti-cathode covering 31. When the fast electrons strike the anti-cathode, hard X-rays are produced which penetrate the beryllium block 32 and cause neutrons to be released therefrom, which neutrons then act upon the block 34.

It may be that fast electrons and hard X-rays have a similar effect upon beryllium and one may therefore contemplate the making of the covering 31 of the wheel 30 from beryllium, the beryllium block 32 then being dispensed with, so that the neutrons released directly from the beryllium anti-cathode may enter and act upon the block 34.

It is found that when various elements are irradiated with neutrons by the process described above, practically all elements which become radio-active transmute into their own radio-active isotopes, and it becomes difficult to separate these radio-active isotopes from the remaining portion of the element unaffected. In order to achieve separation of the radio-active element from the non-radio-active part thereof the following process may be adopted. This process is based on the fact that if a compound of an element is irradiated by neutrons, and if an atom of the element transmutes into the radio-active isotope, then this atom is freed from the compound. In accordance with the process, a compound of the element it is desired to make radio-active is chosen such that the freed radio-active isotope of the element will not interchange with the combined atoms of the element within the compound, whereby the freed isotope may be chemically separated from the irradiated compound. Very often the element whose radio-active isotope is to be isolated, can be conveniently irradiated in the form of a compound in which it is bound to carbon. Thus in the case of iodine compounds such as iodoform or ethyl iodide, the radio-active iodine isotope may be chemically separated off from the original iodine compound in the form of free iodine.

In order to protect the radio-active iodine isotope a small amount of normal iodine may be dissolved in the organic iodine compound before irradiation or after irradiation but before separation.

What I claim and desire to secure by Letters Patent of the United States is:-

CLAIMS

24. A method of generation of radio-active substances, comprising the steps of producing a neutron radiation and subjecting the substance to be made radio-active to such radiation.

25. A method of generation of radio-active substances comprising the steps of projecting fast ions of an element into a quantity of an element at rest to produce neutron radiation, and subjecting the substance to be made radio-active to such radiation.

26. A method of generation of radio-active substances comprising the steps of projecting fast ions of a light element into a quantity of a light element at rest thereby to produce neutron radiation, and subjecting the substance to be made radio-active to said radiation.

27. A method of generation of radioactive substances comprising the steps of accelerating diplogen ions in the form of positive rays, causing such rays to fall upon light elements thereby to produce neutron radiation, and causing such neutron radiation to fall upon the substance to be made radio-active.

28. A method of generation of radio-active substances comprising accelerating diplogen ions in the form of positive rays, causing such rays to fall upon diplogen thereby to produce neutron radiation, and causing such neutron radiation to fall upon the substance to be made radio-active.

29. A method of generation of radio-active substances comprising the steps of energising to a very great extent a quantity of an element to cause the nuclei thereof to collide and thereby to produce neutron radiation, and subjecting the substance to be made radio-active to such neutron radiation.

30. A method of generation of radio-active substances comprising the steps of generating heating rays of great intensity, subjecting a quantity of a light element to the action of said rays thereby to produce neutron radiation from said light element, and allowing such neutron radiation to fall upon the substance to be made radio-active.

31. A method of generation of radio-active substances comprising the steps of generating cathode rays of great intensity, subjecting a quantity of an element to the action of said rays thereby to produce neutron radiation from said element and allowing such neutron radiation to fall upon the substance to be made radio-active.

32. A method of generation of radio-active substances comprising the steps of producing a fast electron stream, directing such stream to fall upon an anti-cathode of beryllium thereby to produce neutron radiation, and subjecting to said neutron radiation the substance which is to be made radio-active.

33. A method of generation of radio-active substances comprising the steps of producing a fast electron stream, directing such stream to fall upon an anti-cathode to produce hard X-rays, allowing such X-rays to fall upon a body of an element having a dissociable neutron thereby to produce neutron radiation therefrom, and subjecting the substance to be made radio-active to said neutron radiation.

34. A method of generation of radio-active substances comprising the steps of producing a fast electron stream, directing such stream to fall upon an anti-cathode to produce hard X-rays, allowing such X-rays to fall upon a body of beryllium thereby to produce neutron radiation therefrom, and subjecting the substance to be made radio-active to said neutron radiation.

35. Apparatus for the generation of radio-active materials comprising a target of a substance, means for causing the latter to undergo a nuclear transmutation process thereby to produce neutron radiation, and a body of the material which is to be made radio-active located to intercept said neutron radiation.

36. Apparatus for the generation of radio-active materials comprising a target of a substance, means for producing and accelerating positive ions of a light element said means being arranged to project said ions onto the target, and a body of the material which is to be made radio-active, located adjacent said target to intercept the neutron radiation therefrom.

37. Apparatus for the generation of radio-active materials comprising a container for a body of diplogen, at least one positive ray tube mounted to emit positive rays into said

container said tube containing diplogen, and a body of substance to be made radio-active located adjacent said container to intercept the neutron radiation therefrom.

38. Apparatus for the generation of radio-active materials comprising a container for a body of diplogen, at least one positive ray tube containing diplogen, means for accelerating the rays from said tube said means being mounted to direct the accelerated rays into the container, and a body of substance to be made radio-active located adjacent said container to intercept the neutron radiation therefrom.

39. Apparatus for the generation of radio-active materials comprising a target of a substance, means for projecting onto said target a corpuscular heating ray of great intensity, and a body of the substance which is to be made radio-active located adjacent said target to intercept the neutron radiation therefrom.

40. Apparatus for the generation of radio-active materials comprising a container adapted to be filled with at least one light element, and at least one cathode ray tube adapted for high discharge for short periods, said tube being mounted to project cathode rays into said container, and a body of material which is to be made radio-active located adjacent said container to intercept the neutron radiation therefrom.

41. Apparatus for the generation of radio-active materials comprising a container adapted to be filled with at least one light element, a cathode ray tube arranged to direct rays into said container a circuit through said tube including a condenser and a spark gap device, leads to either side of said condenser, inductances functioning as chokes in said leads, a source of high voltage supply connected to said leads, and a body of the material to be made radio-active

located adjacent said container to intercept the neutron radiation therefrom.

42. Apparatus for the generation of radio-active materials comprising means for producing a fast electron stream, an anti-cathode for intercepting such stream to produce hard X-rays, a body of an element having a dissociable neutron arranged to encounter the hard X-rays and a body of the material to be made radio-active located adjacent said elemental body to intercept the neutron radiation therefrom.

43. Apparatus for the generation of radio-active materials comprising means for producing a fast electron stream, an anti-cathode for intercepting such stream to produce hard X-rays, a beryllium block arranged to encounter the hard X-rays and a body of the material to be made radio-active located adjacent said block to intercept the neutron radiation therefrom.

44. Apparatus for the generation of radio-active substances comprising an impulse generator, a discharge tube connected in circuit with said impulse generator device, said tube being arranged to produce a fast cathode stream, an anti-cathode of a heavy element containing substance arranged to intercept the cathode stream to produce hard X-rays, a block of an element having a dissociable neutron positioned to be irradiated by the hard X-rays, and a body of substance to be made radio-active located adjacent the said block to intercept the neutron rays therefrom.

45. Apparatus for the generation of radio-active substances comprising an impulse generator, a discharge tube connected in circuit with said impulse generator device, said

tube being arranged to produce a fast cathode stream, an anti-cathode of a heavy element containing substance arranged to intercept the cathode stream to produce hard X-rays, a beryllium block positioned to be irradiated by the hard X-rays, and a body of substance to be made radio-active located adjacent the beryllium block to intercept the neutron rays therefrom.

46. Apparatus for the generation of radio-active substances comprising an impulse generator, a spark gap device connected in circuit with said impulse generator, a discharge tube connected in circuit with the impulse generator and spark gap device, said tube being arranged to produce a fast cathode stream, an anti-cathode of a heavy element arranged on the periphery of a wheel, means for rotating the wheel and for introducing cooling medium thereto, said wheel being located so that a portion of its periphery intercepts said cathode ray stream to produce hard X-rays, a beryllium block positioned to be irradiated by the hard X-rays, and a body of substance to be made radio-active located adjacent the beryllium block to intercept the neutron rays therefrom.

47. A method of generating a radio-active element from elements which transmute in the process into their own radio-active isotopes, consisting in irradiating a compound of the element which compound will not interchange the combined atoms of the element for the isotopic atoms of the same element freed from the compound in the process.

48. A method of generating a radio-active element from elements which transmute in the process into their own radio-active isotopes, consisting in irradiating with neutrons

a compound of the element which compound will not interchange the combined atoms of the element for the isotopic atoms of the same element freed from the compound in the process.

49. A method of generating a radio-active element from elements which transmute in the process into their own radio-active isotopes, consisting in irradiating a compound in which the element is bound to carbon, which compound will not interchange the combined atoms of the element for the isotopic atoms of the same element freed from the compound in the process.

50. A method of generating a radio-active element from elements which transmute in the process into their own radio-active isotopes, comprising the steps of projecting fast ions of a light element into a quantity of a light element at rest thereby to produce neutron radiation, and subjecting to such radiation a compound of the element to be made radio-active, which compound will not interchange the combined atoms of the element for the isotopic atoms of the same element freed from the compound in the process.

51. A method of generating a radio-active element from elements which transmute in the process into their own radio-active isotopes, comprising the steps of producing a fast electron stream, directing such stream to fall upon an anti-cathode to produce hard X-rays, allowing such X-rays to fall upon a body of an element having a dissociable neutron thereby to produce neutron radiation therefrom and subjecting to such neutron radiation a compound of the element to be made radio-active, which compound will not interchange the combined atoms of the element for the isotopic atoms of the same element freed from the compound in the process.

R E M A R K S.

With a view to meeting the Examiner's objections raised in the current Office Action a careful revision has been made throughout of the disclosure in this case. It is now submitted that the descriptive portion of the Specification is clear to a person skilled in the particular art. In a separate letter to the Official Draughtsman the insertion of additional reference letters in the drawings has been requested so that generally the disclosure now becomes more constructive and rather less theoretical. It will be observed that a considerable portion of the Specification is without a counterpart in the newly revised Specification. Furthermore it is desired to cancel all but Figures 1 to 6 of the drawings. It is to be understood that the Figures of the drawings and also the corresponding portion of the Specification have been cancelled without prejudice to the lodging of a Divisional Application at a later date.

The new claims submitted herewith have been drawn in accord with the usual United States practice, and it is now earnestly requested that the Examiner issue an Action upon the merits of this case.

Applicant has duly completed a Power of Attorney which is being forwarded herewith.

Very respectfully,

Apparatus for Nuclear Trans-mutation

US Patent

Compare Serial #
10500 and
10500

Probably from E-53

COPY

UNITED STATES SPECIFICATION

of

the invention of Dr. LEO SZILARD,

for

"Apparatus for Nuclear Transmutation"

Serial No. 105000 of 1935.

HASELTINE, LAKE & CO.
CHARTERED PATENT AGENTS,
28, SOUTHAMPTON BUILDINGS,
LONDON.
AND AT NEW YORK, N.Y.
U.S.A.
ALSO
NEWCASTLE-ON-TYNE,
THE SUN INSURANCE BUILDINGS,
COLLINGWOOD STREET.

S P E C I F I C A T I O N

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN that I, LEO SZILARD, a citizen of Germany and Hungary, residing at 500 Riverside Drive, New York City, in the County of New York, and State of New York, United States of America, have invented certain new and useful "Apparatus for Nuclear Transmutation" of which the following is a Specification:-

According to my invention radio-active elements may be produced from light and heavy elements when such elements are subjected to the effect of a neutron bombardment. Such a neutron bombardment may be effected by causing accelerated heavy hydrogen (diplogen) atoms or nuclei to collide with diplogen or other light elements.

Other features of the invention will appear in the detailed description referring to the drawings which now follows, and will be more particularly pointed out in the claims.

In the drawings,

Figure 1 represents a sectional elevation of an apparatus for carrying out the invention,

Figure 2 shows a more constructional lay-out of the apparatus of Figure 1,

Figure 3 indicates diagrammatically the circuit arrangement of modified apparatus for the performance of the invention,

Figure 4 is a more detailed view corresponding to Figure 3,

Figure 5 shows the circuit arrangements for further modified apparatus, and

Figure 6 is a sectional view of apparatus intended to co-operate with that shown in Figure 5.

Referring first to Figure 1 of the drawings, 11 is an electrical discharge tube adapted to project a beam 12 of fast diplogen ions. The tube 11 is filled with diplogen and an anode A and cathode B are provided for connection to a source of high voltage. The diplogen ions are thus projected at high speed and pass through the cathode B. The ions fall on a substance 13 in a sealed container 13A. The substance 13 consists, for instance, of gaseous diplogen, or a diplogen compound or lithium. The collision of the fast diplogen ions with the substance 13 causes transmutation, i.e. a nuclear reaction of the diplogen ion with an atom of the target. The substance 13 is surrounded by a thick layer 14 containing the element or substance which it is desired to transmute into a radioactive element or substance. In order to have a high efficiency, the thickness of the layer 14 has to be sufficiently great, compared with the mean free path of the neutron, to prevent escape of any of the neutrons.

Figure 2 shows in more detail the electrical discharge tube 11 referred to in Figure 1. The tube essentially consists of a main portion 16 serving to accelerate the diplogen ions and an auxiliary tube 11T for initiating the flow. 11A is the anode and 15 the cathode of the auxiliary tube, diplogen being admitted thereto through the inlet 13B and being pumped away through the outlet 14A. The flow initiated by the auxiliary tube is accelerated by passage through the main tube 16 which is maintained exhausted by suction outlets 14^1 and 14^2, and which has a high potential gradient, there being a million volt potential difference between the ends of the tube. The accelerated diplogen ions emerge through the neck 14^3 of the tube 16 and collide with the substance 13 as described with reference to Figure 1 of the drawings.

If the substance 13 is a light element for instance diplogen, or lithium, then the bombardment by the accelerated diplogen ion results in emission of uncharged particles of mass of the order of magnitude of the mass of a proton. Such uncharged nuclei i.e. neutrons, penetrate even substances containing the heavier elements without ionisation losses, and will cause the formation of radio-active substances in the layer 14 exposed to them. It is to be observed that by the method so far described, the ionisation losses on collision of the diplogen nuclei with light nuclei are comparatively small due to the orbited electrons of light elements and also that the substance to be made radio-active is irradiated with neutrons i.e. uncharged nuclei, which pass through even heavy elements without ionising them. The substance 14 exposed for treatment by the neutron radiation may be in the form of an organic material for the purpose of carrying out separation of the generated radio-active part, as described more fully hereinafter.

The method for the production of neutrons just described consists essentially of discharging particles through matter which is at rest. A diplon (adiplogen nucleus) shot into diplogen at rest will in a large proportion of cases lose its energy by ionising the diplogen and cause no transmutation. In the following I shall describe a method by which a great concentration of energy is produced in a body of diplogen or other light element or elements, the energy concentration being such as to cause the nuclei in the body of substance to collide with one another. Under these conditions, which need be maintained only momentarily, neuton radiation is produced and can be used for the treatment of an element to render it radio-active.

Apparatus for this purpose is illustrated in Figure 3, 52 being an electric condenser which is fed through inductive chokes 53 and 54, from a high potential supply. One side of the condenser is connected to a spark gap device 51 which is in turn connected with the cathode 42 of a discharge tube 41. In Figure 4 this discharge tube 41 is shown on a larger scale, the electrical arrangement for operating the tube being the same as shown in Figure 3. The discharge tube is formed as a cathode ray tube, there being the cathode 42 and an anode connection 42A, to allow the spherical shell 42B onto which the tube 41 connects, to act as the anode. The end of the tube 41 is sealed off at 42C by means of a thin metallic window. At the centre of the spherical shell 42B is a spherical container 44 filled with diplogen. As indicated in the drawings more than one of the cathode ray tubes 41 may be mounted radially upon the spherical shell 42B, so that the emergent corpuscular rays from the said cathode ray tubes focus upon the container 44. In operation a high potential is supplied to the condenser 52 through the chokes 53 and 54, and when such potential reaches a predetermined critical value the condenser discharges and causes a spark to pass between the poles of the spark gap device 51. The cathode ray tube or tubes 41 are thereby energised and corpuscular cathode rays are produced. These rays serve as heating rays and cause the diplogen contained in the container 44 to have its energy contents raised up to a very high value for a short period. Such energy concentration produces interaction of the diplogen nuclei with the consequent formation of neutron rays.

Cathode rays have been suggested to perform the heating or energy concentrating action referred to above, but it will be understood that protons or heavier ions might instead be used. Furthermore, the container 44 might be filled with diplogen alone or lithium hydride, or other compounds of hydrogen and lithium, or other compounds of hydrogen or diplogen with a third light element. The container 44 encloses the transmutation space from which the neutron rays emerge and by surrounding the space with substances to be treated for the purposes of making them radio-active, such substances may be bombarded with neutrons in the same way as was described with reference to Figures 1 and 2 of the drawings.

Neutron radiation may also be produced by the action of X-rays upon an element having a dissociable neutron at the prevailing voltage, and apparatus for carrying out this process will now be described with reference to Figure 5 of the drawings.

In Figure 5, 1 is the primary of a transformer, the secondary 2 of which is connected to the junctions 3 and 4. The junction 3 is connected to the cathode 8 of the rectifier tube 5 and to the anode 7 of the rectifier tube 6. The junction 4 is connected to the cathode 9 of the rectifier tube 10 and to the anode 11 of the rectifer tube 12. The cathodes 13 and 14 are connected to each other and to earth. The anodes 15 and 16 are connected at 17, and from this point are connected to the pole 18 of the impulse generator 20, the pole 19 of which is connected to earth. The impulse generator 20 is built of condensers 21, resistances 22 and spark-gap devices 23.

The impulse generator and rectifying unit shortly described above, are known components adapted to give an extremely high voltage for a fraction of a second. With such a system voltages up to 3 million volts have been obtained. The negative side of the impulse generator is connected to a spark gap device 25, which in turn is connected with the cathode 26 of the discharge tube 24. The latter is built up from rings 24A of which only a few are shown in the drawing. It will, however, be understood that the rings are continuous to enclose a space which is exhausted through the outlet 24B. The anode 27 of the tube is connected to earth and is formed by a metallic window. A body of material 28 is arranged at the external side of the window 27.

When the impulse generator operates to produce discharge between the cathode 26 and anode 27 of the tube 24, fast electrons penetrate the anode 27 and impinge upon the body 28. The latter when formed of Bi or Pb or some other heavy element, acts as an anti-cathode and hard X-rays are produced.

In Figure 6 of the drawings there is shown the lower portion of the discharge tube 24 with a device therebeneath for utilising the hard X-rays capable of being produced with the aid of the fast electrons emerging through the anode 27 of the tube 24. The device consists of a block 34 of the element which is to be made radio-active, a block 32 of an element with a dissociable neutron, being located therein. An aperture is formed in both the blocks 32 and 34 to allow entry of the rays from the tube 24 above. The blocks 32 and 34 are also arranged to accommodate a wheel 30 and axle 35.

The wheel 30 at its periphery carries a covering of tungsten or lead 31. The covering 31 acts as an anti-cathode and is cooled with water introduced along the bearing for the axle 35. The block 34 may be in the form of a cube having a length of side of 50 cms., whilst the block 32 can also be of cube form with a side of 25 cms. For the sake of example the block 34 may be formed of iodine or arsenic or other material which lends itself to being made radio-active. The block 32 may be of metallic beryllium. In order that an isotopic separation as described hereinafter may be performed after irradiation the material of the block 34 may be in the form of an organic compound. A voltage of 3 million volts may be used for the discharge tube and in operation the wheel 30 is rotated so that electrons passing through the anode 27 of the tube 24 hit the rotating anti-cathode covering 31. When the fast electrons strike the anti-cathode, hard X-rays are produced which penetrate the beryllium block 32 and cause neutrons to be released therefrom, which neutrons then act upon the block 34.

It may be that fast electrons and hard X-rays have a similar effect upon beryllium and one may therefore contemplate the making of the covering 31 of the wheel 30 from beryllium, the beryllium block 32 then being dispensed with, so that the neutrons released directly from the beryllium anti-cathode may enter and act upon the block 34.

It is found that when various elements are irradiated with neutrons by the process described above, practically all elements which become radio-active transmute into their own radio-active isotopes, and it becomes difficult to separate these radio-active isotopes from the remaining portion of the element unaffected. In order to achieve separation of the radio-active element from the non-radio-active part thereof the following process may be adopted. This process is based on the fact that if a compound of an element is irradiated by neutrons, and if an atom of the element transmutes into the radio-active isotope, then this atom is freed from the compound. In accordance with the process, a compound of the element it is desired to make radio-active is chosen such that the freed radio-active isotope of the element will not interchange with the combined atoms of the element within the compound, whereby the freed isotope may be chemically separated from the irradiated compound. Very often the element whose radio-active isotope is to be isolated, can be conveniently irradiated in the form of a compound in which it is bound to carbon. Thus in the case of iodine compounds such as iodoform or ethyl iodide, the radio-active iodine isotope may be chemically separated off from the original iodine compound in the form of free iodine. In order to protect the radio-active iodine isotope a small amount of normal iodine may be dissolved in the organic iodine compound before irradiation or after irradiation but before separation.

What I claim and desire to secure by Letters Patent of the United States is:-

24. A method of generation of radio-active substances, comprising the steps of producing a neutron radiation and subjecting the substance to be made radio-active to such radiation.

25. A method of generation of radio-active substances comprising the steps of projecting fast ions of an element into a quantity of an element at rest to produce neutron radiation, and subjecting the substance to be made radio-active to such radiation.

26. A method of generation of radio-active substances comprising the steps of projecting fast ions of a light element into a quantity of a light element at rest thereby to produce neutron radiation, and subjecting the substance to be made radio-active to said radiation.

27. A method of generation of radio-active substances comprising the steps of accelerating diplogen ions in the form of positive rays, causing such rays to fall upon light elements thereby to produce neutron radiation, and causing such neutron radiation to fall upon the substance to be made radio-active.

28. A method of generation of radio-active substances comprising accelerating diplogen ions in the form of positive rays, causing such rays to fall upon diplogen thereby to produce neutron radiation, and causing such neutron radiation to fall upon the substance to be made radio-active.

29. A method of generation of radio-active substances comprising the steps of energizing to a very great extent a quantity of an element to cause the nuclei thereof to collide and thereby to produce neutron radiation, and

subjecting the substance to be made radio-active to such neutron radiation.

30. A method of generation of radio-active substances comprising the steps of generating heating rays of great intensity, subjecting a quantity of a light element to the action of said rays thereby to produce neutron radiation from said light element, and allowing such neutron radiation to fall upon the substance to be made radio-active.

31. A method of generation of radio-active substances comprising the steps of generating cathode rays of great intensity, subjecting a quantity of an element to the action of said rays thereby to produce neutron radiation from said element and allowing such neutron radiation to fall upon the substance to be made radio-active.

32. A method of generation of radio-active substances comprising the steps of producing a fast electron- stream, directing such stream to fall upon an anti-cathode of beryllium thereby to produce neutron radiation, and subjecting to said neutron radiation the substance which is to be made radio-active.

33. A method of generation of radio-active substances comprising the steps of producing a fast electron stream, directing such stream to fall upon an anti-cathode to produce hard X-rays, allowing such X-rays to fall upon a body of an element having a dissociable neutron thereby to produce neutron radiation therefrom, and subjecting the substance to be made radio-active to said neutron radiation.

34. A method of generation of radio-active substances comprising the steps of producing a fast electron stream, directing such stream to fall upon an anti-cathode to produce hard X-rays, allowing such X-rays to fall upon a body

of beryllium thereby to produce neutron radiation therefrom, and subjecting the substance to be made radio-active to said neutron radiation.

35. Apparatus for the generation of radio-active materials comprising a target of a substance, means for causing the latter to undergo a nuclear transmutation process thereby to produce neutron radiation, and a body of the material which is to be ade radio-active located to intercept said neutron radiation.

36. Apparatus of the generation of radio-active materials comprising a target of a substance, means for producing and accelerating positive ions of a light element said means being arranged to project said ions onto the target, and a body of the material which is to be made radio-active, located adjacent said target to intercept the neutron radiation therefrom.

37. Apparatus for the generation of radio-active materials comprising a container for a body of diplogen, at least one positive ray tube mounted to emit positive rays into said container said tube containing diplogen, and a body of substance to be made radio-active located adjacent said container to intercept the neutron radiation therefrom,.

38. Apparatus for the generation of radio-active materials comprising a container for a body of diplogen, at least one positive ray tube containing diplogen, means for accelerating the rays from said tube said means being mounted to direct the accelerated rays into the container, and a body of substance to be made radio-active located adjacent said container to intercept the neutron radiation therefrom.

39. Apparatus for the generation of radio-active materials comprising a target of a substance, means for projecting onto said target a corpuscular heating ray of great intensity, and a body of the substance which is to be made radio-active located adjacent said target to intercept the neutron radiation therefrom.

40. Apparatus for the generation of radio-active materials comprising a container adapted to be filled with at least one light element, and at least one cathode ray tube adapted for high discharge for short periods, said tube being mounted to project cathode rays into said container, and a body of material which is to be made radio-active located adjacent said container to intercept the neutron radiation therefrom.

41. Apparatus for the generation of radio-active materials comprising a container adapted to be filled with at least one light element, a cathode ray tube arranged to direct rays into said container a circuit through said tube including a condenser and a spark gap device, leads to either side of said condenser, inductances functioning as chokes in said leads, a source of high voltage supply connected to said leads, and a body of the material to be made radio-active located adjacent said container to intercept the neutron radiation therefrom.

42. Apparatus for the generation of radio-active materials comprising means for producing a fast electron stream, an anti-cathode for intercepting such stream to produce hard X-rays, a body of an element having a dissociable neutron arranged to encounter the hard X-rays and a body of the material to be made radio-active located

adjacent said elemental body to intercept the neutron radiation therefrom.

43. Apparatus for the generation of radio-active materials comprising means for producing a fast electron stream, an anti-cathode for intercepting such stream to produce hard X-rays, a beryllium block arranged to encounter the hard X-rays and a body of the material to be made radio-active located adjacent said block to intercept the neutron radiation therefrom.

44. Apparatus for the generation of radio-active substances comprising an impulse generator, a discharge tube connected in circuit with said impulse generator device, said tube being arranged to produce fast cathode rays, an anti-cathode of a heavy element containing substance arranged to intercept the cathode rays to produce hard X-rays, a block of an element having a dissociable neutron positioned to be irradiated by the hard X-rays, and a body of substance to be made radio-active located adjacent the said block to intercept the neutron rays therefrom.

45. Apparatus for the generation of radio-active substances comprising an impulse generator, a discharge tube connected in circuit with said impulse generator device, said tube being arranged to produce a fast cathode stream, an anti-cathode of a heavy element containing substance arranged to intercept the cathode stream to produce hard X-rays, a beryllium block positioned to be irradiated by the hard X-rays, and a body of substance to be made radio-active located adjacent the beryllium block to intercept the neutron rays therefrom.

46. Apparatus for the generation of radio-active substances comprising an impulse generator, a spark gap device connected in circuit with said impulse generator, a discharge tube connected in circuit with the impulse generator and spark gap device, said tube being arranged to produce a fast cathode stream, an anti-cathode of a heavy element arranged on the periphery of a wheel, means for rotating the wheel and for introducing cooling medium thereto, said wheel being located so that a portion of its periphery intercepts said cathode ray stream to produce hard X-rays, a beryllium block positioned to be irradiated by the hard X-rays, and a body of substance to be made radio-active located adjacent the beryllium block to intercept the neutron rays therefrom.

47. A method of generating a radio-active element from elements which transmits in the process into their own radio-active isotopes, consisting in irradiating a compound of the element which compound will not interchange the combined atoms of the element for the isotopic atoms of the same element freed from the compound in the process.

48. A method of generating a radio-active element from elements which transmute in the process into their own radio-active isotopes, consisting in irradiating with neutrons a compound of the element which compound will not interchange the combined atoms of the element for the isotopic atoms of the same element freed from the compoundin the process.

49. A method of generating a radio-active element from elements which transmute in the process into their own radio-active isotopes, consisting in irradiating a compound in which the element is bound to carbon, which compound will not interchange the combined atoms of the element for the isotopic atoms of the same element freed from the compound

in the process.

50. A method of generating a radio-active element from elements which transmute in the process into their own radio-active isotopes, comprising the steps of projecting fast ions of a light element into a quantity of a light element at rest thereby to produce neutron radiation, and subjecting to such radiation a compound of the element to be made radio-active, which compound will not interchange the combined atoms of the element for the isotopic atoms of the same element freed from the compound in the process.

51. A method of generating a radio-active element from elements which transmute in the process into their own radio-active isotopes, comprising the steps of producing a fast electron stream, directing such stream to fall upon an anti-cathode to produce hard X-rays, allowing such X-rays to fall upon a body of an element having a dissociable neutron thereby to produce neutron radiation therefrom and subjecting to such neutron radiation a compound of the element to be made radio-active, which compound will not interchange the combined atoms of the element for the isotopic atoms of the same element freed from the compound in the process.