IN THE UNITED STATES PATENT OFFICE

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

APPARATUS FOR NUCLEAR
TRANSMUTATION

## AFFIDAVIT OF LEO SZILARD

STATE OF NEV YORK 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 Physies with the teaching staff of that university.

When I filed the British provisional application on March 12, 1934, it wes 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 thet some of the particles other than alpha particles might (or might not) produce radioactivity wes 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. Permi produced the neutrons with which he demonstrated his discovery by bombarding berylliura 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 rainutes if he had known that neutrons induce radioaetivity 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 elenent 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 ruch more efficient than the production of radio-activity by alpha particles previously demonstrated by Jollot, he would not have attempted to make the experiment with neutrons even if he had thought that neutrons might possibly produce radioactivity.

In view of the fact that neutron sources which are maintained by bombarding beryllium with elpha 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 radioactivity, 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 raason 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 inwhen creasing thickness of the layer. At the time that 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 wes 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 atetention, 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 radioactive 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 tisolated 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 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 18 th day of October, 1938.

Madeline Sigward
Notary Public
NOTARY PUBLTC, Queens Count
Quecas Cornty Cherte's Mo. 1873
Quecns Commy Ragistanes 1 NO .1485
Certiicate filed La New Yoriz County
New York Co. Cheris's No. 378
New York Co. Ragisters No. OS 243
Commisfiou expires March 30, 1940

Applicant: LEO SZILARD. Serial No: 10,500

Filed: Maroh 11, 1935
Div. 56. Room 4725.

Apparatus for Nuclear
Transmutation.

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

Sir,
In response to the official Action of 38 th 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 desoription 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 elenents when such elements are subjected to the effect of a neutron bombardment. Such a neutron bombardnent may be effected by causing accelerated heavy hyarogen (diplogen) atoms or nuolei to collide with diplogen or other light elements.

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

In the drawings,
Pigure 1 represents a sectional elevation of an apparatus for carrying out the invention,

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

Figure 3 indicates diagramatioally the eirouit arrangenent of modified apparatus for the perfornance of the invention,

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

Figure 5 shows the cirouit 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 2 of the arawings, 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 oathode $B$ 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 lons with the substance 13 oauses transmutation, i.e. a nuclear reaction of the diplogen ion with an a tom 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 thiekness 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 12 for initiating the flow. 11A is the anode and 15 the cathode of the auxiliary tube, diplogen being admitted thereto through the inlet 138 and being pumped away through the outiet 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 neak $14^{3}$ 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 oause 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 elenents 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 essentialiy of discharging partioles 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 fonising the diplogen and cause no transmutation. In the following I shall describe a method by whioh a great concentration of energy is produced in a boaty of diplogen or other light element or elements, the energy concentration being such as to cause the nuclel 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-ac tive.

Apparatus for this purpose is illustrated in Figure 3, 52 being an electric condenser which is ped 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 tum oonnected with the cathode 42 of a discharge tube 42. In Figure 4 this alscharge 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 eathode 42 and an anode connection 42 A , to allow the spherical shell 423 onto which the tube 41 comnects, to act as the anode. The end of the tube 41 is sealed off at 420 by means of a thin metallio window, At the centre of the spherical shell $42 B$ is a spherical container 44 filled with diplogen. As indicated in the drawings more than one of the eathode ray tubes 41 may be mounted radially upon the spherical shell 42 B , so that the emergent corpuscular rays from the said eathode 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 predetemined 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 thereloy energized and corpuscular cathode rays are produced. These rays serve as heating rays and eause 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 neubror 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. Furthemore, the container 44 might be filled with diplogen alone or 11 thium hydride, or other compounds of hydrogen and lithiw, 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 prooess will now be described with reference to Figure 5 of the arawings.

In Pigure 5, 1 is the prinary of a transfomer, the secondary 2 of which is connected to the junctions 3 and 4. The junotion 3 is connected to the a thode 8 of the reotifiar 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 21 of the rectifiex tube 12. The cathodes 13 and 14 are connected to each other and to earth. The anodes 15 and 16 are conneoted 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 impuise 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 eathode 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 $24 B$. The anode 27 of the tube is connected to earth and is formed by a metallic window. A boay 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 eleotrons penetrate the anode, 27 and frapinge upon the body 28. The latter when formed of Bi or Pb or somebther heavy elenent, acts as an anti-cathode and hard X-rays are produced.

In Figure 6 of the arawings 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 energing through the ahode 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 looated therein. An aperture is formed in both the blocks 32 and 34 to allow entry of the rays from the tube 24 above. The blooks 32 and 34 are also arranged to accomnodate 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-cathote 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 al.so 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 metial which lends itself to being made radio-active. The block 32 may be of metallic berylliwa. In order that an isotopic separation as described hereinafter may be performed after irradiation the material of the block 34 may be in the fom 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-oathode oovering 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 blook 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 beryilium blook 32 then being aispensed with, so that the neutrons released directily from the bexyllium anticathode may enter and act upon the block 34.

It is found that when various elements are irradiated with neubrons by the process described above, practically all elements which become radiomative transmute into their own radio-sotive isotopes, and it becomes difeicult to separate these radio-aotive isotopes from the remaining portion of the element unaffected, In ordar to achieve separation of the radio-active element from the non-radioactive 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 elenent 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 ohemically separated off from the original iodine compound in the form of free iodine.

In order to protect the radio-active iodine isotope a grall 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:-

## C LAIMS

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 radioactive to such radiation.
26. A method of generation of radio-active substances comprising the steps of projecting fast ions of a light el ment 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 elenents the reby to produce neutron radiation, and causing such neutron radiation to fall upon the substanee 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 nuelei 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-gotive substances comprising the steps of generating heating rays of great Intensity, subjecting a quantity of a light olement to the daction of said rays thereby to produce neutron radiation erom 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 compr ising 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 me thod 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 neatron 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 subjeoting the substance to be made radio-active to said neutron radiation.
34. A me thod of generation of radio-active substances comprising the steps of produc ing a fast electron stream, directing such stream to rall upon an antimeathode to produce hard $X$-rays, allowing such $X-r a y s$ 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 the reby to produee 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 saidions onto the target, and a body of the material which is to be made radioaotive, looated adjacent said target to intercept the neutron radiation therefrom.
37. Apparatus for the generation of radio-active meterials 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 looated adjacent said container to intereept the neutron radiation therefrom.
38. Apparatus for the generation of radio-active materials conprising a container for a boay of diplogen, at least one positive ray tube contatning 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 on to 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 athode 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-aotive 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 elenent, a cathode rey 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 ohokes 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 $\bar{x}-r a y s$ 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 materisls comprising means for produeing 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 radioactive located adjacent said block to intereept the neutron radiation therefrom.
44. Apparatus for the generation of radio-active substances comprising an impulse generator, a disoharge tube connected in eircuit with said impulse generator device, said tube being arranged to produce a fast eathode 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 elenent containing substance arranged to intercept the eathode stream to produce hard $X$-rays, a beryllium bloek 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 interoept the ne utron rays therefrom.
46. Apparatus for the generation of radio-active substances comprising an impulse generator, a spark gap device connected in eircuit 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 loested so that a portion of its periphery intercepts said cathode ray strean to produce hard $X$-rays, a beryilium blook 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 radioactive isotopes, consisting in irradiating a compound of the elenent which compound will not interchange the combined atoms of the element for the isotopic atoms of the same element freedfrom 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 ol ement thich conpound will not interehange the combined ators of the element for the isotopie atons of the same element freed from the compound in the proeess.
49. A mothod of generating a rado-aetive element from elements which transmute in the proeess into their own radioactive isotopes, convisting in ixradiating a compound in which the element is bound to earbon, which coupound wil. not interchange the combined atoas of the elenont foy the isotopic atoms of the same element freed from the compound in the proeess.
50. A method of generating a radomative element fran elenents whioh transaute in the proeess into their own radionactive isotopes, comprising the steps of projecting fast ions of a light element into a guantity of a 21 gh t alemant at rest thereby to produce neutron radiation, and subjecting to such radiation a oompound of the elemant to be made radio-active, which conpound wili not interchange the combiad atoms of the element for the isotopis atoms of the awne dienent freed from the eampound in the process.
51. A method of generating a radio-active element from elements Which transmute in the proeess into their own rado-setsve iaotopes, comprising the stops of produoing a fast electron strean, alrecting auch strean to fall upon an
 fall upon a body of an alement having a dissociable neutron thereby to produee neutron madation thererirom and subjecting to such neutron madiation a compound of the element to be made radsooactive, wich compound wilk not interchange the coabined atons of the elenent for the isotopic atoms of the sam element freed from the campound in the proeess.

R $\mathrm{SHARE}_{\mathrm{M}}^{\mathrm{M}}$ 。


With a view to meeting the Exerainer's objections raised in the aurrent office Aation a careful revision has been made throughout of the disclosure in this case. It is now submitted that the desoriptive portion of the Specifioation is olear to a person skilled in the particular art. In a separate letter to the official Draughtsman the insertion of aditional reference letters in the drawinge has been requested so that generaliy the disclosure now becomes more constructive and rather less theoretical. It will be observed that a considerable portion of the speoification is without a counterpart in the newly revised Specification, Furthemore it is desired to cancel all but Pigures 1 to 6 of the drawings. It is to be understood that the Figures of the drawings and also the corresponaing portion of the Specification have been cancelled without prejudice to the Loagiog of a Divisional applioation at a later date.

The new olel通 subnitted herewith have been orawn in accord with the usual United States practice, and it is now earnestiy requasced thet the Examiner issue an Action upon the merits of this oase.

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

$$
\begin{aligned}
& \text { Apparalus fop } \\
& \text { Nuclear Trans - } \\
& \text { Mntalion } \\
& \text { USPatent } \\
& \text { Cmpare Seinal \# } \\
& 1050 \text { and } \\
& 10500
\end{aligned}
$$

of
the invention of Dr. IEO 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.

TO ALL 塭OM TY MAY COMOEAN:

38 IT INOMN that $I$, LTO SZILARD, a citizen of Germany and Eungary, residing at 500 Riverside Drive, New York C1ty, in the County of Wew York, and State of New York, United states of Americe, have invented certain new and userul "Apparatus for Nuelear Transmutation" of whoh the following is a Specilioation:-

Aocording to my invention radio-aotive elenents may be produced from light and heavy elements when such elements are subjeated to the effeot of a noutron bombardment. Such a neutron bombardment may be offected by causing accelerated heavy hydrogen (aiplogen) atoms or nuolel to eollide with 4iplogen or other light eloments.
other features of the invention will appear in the detalled deseription referring to the drawings which now Sollows, and will be more partioularly pointed out in the olalms.

In the drawings,
Tisure 1 represents a sectional olevation of an apparatus for carrying out the invontion,

Figure 2 ahows a more oonstruotional lay-out of the apparatus of \$1eure 1.

Figure 3 indioates diagramatioaly the oircuit arrancement of modified apparatus for the performence of the invention,

Figure 4 is a more detailed view corresponding to "\#gure 3 。

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

Figure 6 is a sectionsl view of epparatus intended to oo-operate with that shown in Figure 5 .

Meferring first to Figure 1 of the arewings, 11 is an oleotrical Alscharge tube adapted to project a beam 22 of fast diplogen ions. The tube 11 is filled with aiplogen and an unode $A$ and eathode 3 are providod for comnection to a source of high voltage. The diplogen

Ions are thus projeeted at high speed and pass through the eathode $B$. The ions fall on a substance 13 in a sealed. container 13A. The substance 13 consists, for instance, of geseous diplogen, or a diplogen compound or lithium. The oollision of the fast diplogen ions with the substance 13 anuses transmutation, 1.e. a nuclear reaction of the aiplogen ion with an ator of the target. The substance 13 is surrounded by a thiok layer 14 containing the element or substance which it is desired to transmute into a radiosotive element or substance. In order to heve a high offlolency, the thiokness 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. Pigure 2 shows in more dotail the electricol discharge tube 11 referred to in Figure 1. The tube essentially consists of a mein portion 16 serving to accelerate the diplogen ions and an auxiliary tube 117 for initiating the 110\%. 11A is the anode and 15 the cathode of the auxiliary tube, diplogen being admitted thereto through the inlet 138 and boing pumped away through the outlet 14 A . The flow initiated by the auxiliary tube is accelerated by passage through the main tube 26 which is maintained exhausted by suction outlets $14^{1}$ and $14^{2}$, and whioh has a high potential gradient, there being a million volt potential difference between the ends of the tube. The acoelerated aiplogen ions amerge through the neok $14^{3}$ of the tube 16 and collide with the substance 13 as described with reference to Figure 2 of the arawings.

If the substance 13 is a 11 ght olement for instance diplogen, or lithium, then the bomberdment by the accelerated diplogen ion results in emission of uncharged partioles of mass of the order of magnitude of the mess of a proton. Such uncharged nuelei $1 . e$. neutrons, penetrate even substances conteining the heavier elements without ionisation losses, end w111 oause the formation of rallo-nctive substances in the layer 14 exposed to them. It is to be observed that by the method so far desoribed, the ionisation losses on collision of the aiplogen nuclel. with light nucled are oomparetively small tue to the orbited eleotrons of 11 ght elements and also thet the substance to be mede rado-active is irradiated with neutrons i.e. uncharged nuclel, whioh pass through ovon heer 7 elements without lonising them. The substance 14 exposed for treatment by the neutron radiation may be in the form of an organic materlel for the purpose of carrying out separation of the genorated redio-a.otive pert, as deseribed nore fully horeinafter.

The method for the production of neutrons just described consists essentially of alscharging partioles through matter which is at rest. A diplon (adiplogen nueleus) shot into aiplogen at rest wil2 in a large proportion of cases lose its energy by lonising the alplogen and cause no transmutetion. In the following I shell Gesoribe a mothod by whioh a great concentration of energy is produoed in a body of diplogen or other light element or elemonts, the energy conoentration being such as to cause the nuclel in the body of substance to collide with one another. Tndar these oonditions, whioh need be mainteined only momentarily, neuton radiation is produaed and can be used for the treatment of an elament to render it radioaot1ve。

Apparatus for this purpose is illustrated in Ficure 3 , 58 being en eleotric condenser which is fed through inductive ohokes 53 and 54, from a high potentiel supply. One side of the condensor is comnected to a spark eap device 51 which is in turn connected with the onthode 42 of a discharge tube 41. In Figure 4 this aischarge tube 41 is shown on a larger scale, the electrioal arrengement for oparating the tube being the same as shown in Figure 3. The discharge tube is formed as a oathode ray tube, there beling the asthode 42 and an anode connection 42 A , to allow the sphericel shell 423 onto which the tube 41 connaots, to acy as the anode. The end of the tube 41 is soaled ori at 420 by means of a thin motallic window. At the coatre of the spherical shell 423 is a spherical container 44 filled with diplogen. As indicated in the drawings more then one of the athode ray tubes 41 mey be mounted radially upon the spherical shall $42 B$, so that the emergent corpusculer rays from the said cathode ray tubes focus upon the container 44. In opsration a high potential is supplied to the condenser 52 through the chokes 53 and 54, and when such potential reachos a predetermined eriticsi value the condenser discharges and oauses a spark to pass between the poles of the spark gap aevice 51. The oathoae roy 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 enerey contents raised up to a very high value for a short pariod. Such energy concentration produces interaction of the diplogen nuolel with the consagusnt formetion of neutron rays.

Cathode rays have been suggested to perform the heating or enercy concentrating action referred to above, but it will be understood thet protons or heavier ions might instead be used. Furthernore, the container 44 might be filled with diplogen alone or lithium hydride, or other compounds of hyarogen and lithius, or other compounds of hydrogen or diplogen with a third 21 ght slement. The container 44 encloses the transmutation spaee from wich 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 cescribed with reference to Yigures 1 and 2 of the arevings.

Neutron radiation may elso be produeed by the action of Zoroye upon an olement heving a aissocisble neutron the provalling voltage, and apparatus for earrying out this process will now be describod with reference to Pigure 5 of the arawings.

In Pisure 5, 1 is the primary of a transformer, the secondary 2 of wioh is comected to the junotions 3 and 4 . The junction 3 is connected to the eathode 8 of the rectifier tube 5 and to the anode 7 of the rectifier tube 6 . The Junotion 4 is connected to the cathode 2 of the rectifier tube 10 and to the anode 11 of the rectifer tube 12. The eathodes 13 and 14 are connected to asch other and to earth. The onodes 15 and 16 are comneeted at 17 , and from this point are connected to the pole 18 of the impulse generator 20 , the pole 10 of wich is connected to earth. The impulse generator 20 is built of condensers 21 , resistances 82 and spark-gap đevioes 23.

The Lrupulse generator and rectifying unit shortly desortbed above, are known oomponents adapted to give an extramely hich voltage for a fraotion of a secont. 降th such a system voltages up to 3 million volts have been obtained. The negative side of the inpulse ganerator is connected to a spark gap device 25 , which in turn is connected with the aathode 26 of the discharge tube 34. The latter 1 b built up from rings 24A of whioh only a few are shown in the drawing. It will, however, be understood thet the Fings are continuous to enclose a space which is exhausted through the outlet 243 . The anade 27 of the tube is connected to earth and is formed by a motallio window. A body of material 28 is axranged at the external side of the window 27 .

Then the fmpulse generator operates to produce discharge between the cethode 26 and anode 27 of the tube 34 , fast electrons ponetrate tho anode 27 and lapinge upon the body 28. The latter when formod of 31 or Pb or some other heavy element, acts as an antimeathode and herd X-rays are produced.

In Pigure 6 of the drewings there is shown the lower portion of the elscharge tube 24 with a device therebeneath Por utilising the hard I-rays capable of being produced with the ald of the fast electrons emerging through the snode 87 of the tube 24. The device consists of a block 34 of the olement which is to be made padio-aotive, a blook 32 of an element with a dissociable neutron, being loosted therein. an eperture is formed in both the blooks 38 and 34 to ellow ontry of the reys from the tube 34 above, The blocks 32 and 34 are also arranged to accomolate 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. slong 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 blook 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 materisl of the block 34 may be in the form of an orgamie 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 beryllifu 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 38 then being dispensed with, so that the nutrons released directly from the beryllium anti-cathode may enter and act upon the block 34.

It is found that when various elements sre 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 difficuit to separate these radio-active 1 sotopes from the remaining portion of the element unaffected. In order to achleve 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-sctive is chosen such that the freed radio-active isotape of the element will not interchange with the combined atoms of the element within the compound, whoreby the freed isotope may be chemically separated from the irradiated compound. Very often the element whose radio-sctive 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 lodine 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 lodine may be dissolved in the organic iodine compound before irradiation or after irradiation but before separation.

What I clain and cesive to secure by Letters Datent of the United States is:-
24. A mothod of generation of radio-active substances, oomprising the ateps of producing a neutron radiation and subjecting the substance to be made radioneotive to suck radiation.
25. \& mothod of generation of radioactive substanees comprising the steps of projecting fast ions of on elemont into a quantity of an element at rest to produce neutron radietion, and subjeoting the subetance to be male radioactive to such rediation.
26. A method of generation of radio-active substances comprising the steps of projeoting fast ions of a light elenent into a quantity of a light element ot rest thereby to produee neutron radistion, sud subjecting the substance to be made rediometive to sald radiation,
27. A method of generation of radio-sictive substancos comprising the steps of acoelerating diplogon ions in the form of positive rays, causing suoh rays to frall upon 11 eht elements thereby to produce neutron raliation, and causing such neutron radiation to rajl. upon the substance to be made radionetive.
28. A method of genoration of rudio-active substances comprising aocelerating diplogen ions in the form of positive rays, caveing sueh rays to fall upon diplogen thereby to produce neutron reciation, and oausine such neutron radiation to rall upon the aubstance to be made radiongetive.
29. A method of generation of radionective substances comprising the steps of energlaing to a very grest extent a guantity of selement to ocuec the muelel thereor to collide and thereby to produee noutron radietion, and
subjecting the substance to be made radio-active to such neution raciation.
30. A method of cenoration of radio-active substances comprising the steps of generating heating rajs of great intensity, subjeoting a qusintity of a light element to the action of said xays thereby to produee neutron radiation from said 11 tht element, and allowing such noutron radiation to fall upon the aubstance to be mace radio-sotive.
31. A method of generation of radionactive substances © apriaing the steps of generating cathoce rays of great intensity, subjeeting a gquentity of on elenent to the aetion of sald rays thereby to produce noutron radiation from sald element and allowing such neutron raciation to fell upon the substance to be rasde radio-active
32. A method of ceneration of radio-setive substances ocaprising the steps of produeing es fast electron- stream, alreoting such stresm to fall upon an anti-cathode of beryllium thereby to produee neutron radiation, and aubjecting to sala neutron radiation the substance which is to be made radio-aotive.
33. A method of generation of radio-aotive substances coaprising the stepe of produeing a fast electron stream, direoting suoh stream to rall upon an anti-cathode to procuce hard X -rays, allowh eueh Torays to fall upon a bocy of an olement having a asssooleble neutron thereby to produee neutron radiation therefrom, and subjecting the subetance to be made redio-active to sald neutron radiation.
34. A method of generation of radio-aetive substances comprising the steps of produeing e fast eleetron stream, airecting such otrean to foll upon on anti-cathode to produce haxd rerays, allowing such T-rays to foll upon a body
of berydilum thereby to produce neutron raciation therefrom, and aubjecting the substaroe to be made radionaetive to said neutron radiation.
35. Appaxatus for the generation of radio-active naterials oomprising a terget of a substance, means for oasing the latter to uncergo a muclear tranomutation process thereby to produce neutron rediation, and a body of the tutorial which is to be ade radioneetive looated to interoept sosd noutron redsetton.
38. Apparatus of the geaeration of rediometive materials comprising a tarcet or a substance, means for producing and aceclerating positive ions of a 11 ght element sald means being srranged to project mald Lons onto the target, and a body of the material which is to be mace radiosetive, looated ad jecent said target to intergept the neutron radiation therefrom,
37. Apparatus for the generation of radiomactive aatoriala oomprising a containor for a body of alplogen, et least ono positive ray tube mounted to emst positive rays into sald container sale tube containing alplogen, and a body of substance to be made rado-active docated adjacent said contalner to intercept the neutron radietion therefrom,
5. Appagatus for the generation of radioactive materiale comprieing a containor for a body of alplogen, at least one positive ray tube containing aiplogon, means for secelerating the rays from said tube sasd meons being mounted to direet the aceelorated rayb into the container, and a body of subst ance to be made radiometive loeated adjecent sald container to intercopt the neutron radiation therefrom.
39. Apperatus for the generation of madiomactive materials comprising s target of a substance, means ror projecting onto said target a corpusoular heating ray of great intensity, and a body of the gubstance whioh is to be mabe radiomactive Located ajacent said target to Intercept the neutron radiation therefrom.
40. Apparatus for the genoration of radio-netive metorials comprising a container adapted to be fllled with at loast one 11 ht element, and at loast one oathode ray tube adspted for hich eisoharee for short periods, said tube being mounted to projeet eathode reys into seid container; and a body of matorial which is to be made radiomative hooatea adecont suld container to interaept the neutron sad iation therorrom
41. Appuratus for the generation of radio-active materials comprising a oontainer adapted to be rilled with at least one light elament, e cathode ray tube arranged to aireet reys into sald containex a elrouit throuch said tube including a condenser and a spark cap device, leads to either side of said condenser, induetancesfunetioning as ohokes in sald leads, soureo of hich voltage supply oonnected to sald leads, and a boay of the materish to be made racio-aetive loested adjeoent said container to intercept the neutron raciation therefron.

42, Apptratus for the goneration of redio-active ateriale comprising means for produeing a rast electron stream, an enti-cathode for intereepting such stream to produce hard t-rays, a body of on blement having a diswooiable neutron aryenced to encounter the hard K -rays and a body of the materisl to be made radifometive loeated
adjaoent said elomental body to intercept the neutron raciation therefrog.
45. Apparatus for the seneration of radionsetive materials comprising means for proutueing a fast eleotron stiven, an anti-aathode for intercepting sueh strean to produce hard $X-r a y s$, a bery 21 ium blook arranged to encounter the baxd r-rays and a body of the material to be made radioaetive Loeated adjecont besd blook to intercept the neutron radiation therefrom.
44. Apparatua for the generation of radiomactive substances eongrising an impulse gonerator, a aiseharge tube oomeoted in careust with gald impulse gonerator deviee, satd tube being arrenged to produce rast esthode rays, an anti-cathode of a heavy olement oontaining aubstance arranged to 1 interoept the cathode rays to produce hard K-rays, a blook of en element having a Alssociable neutron positioned to be irradiated by the hard z-rays, and a body of substance to be mede radionaotive loonted adjacent the satd blook to intercept the noutron rays therefrom.
45. Apparatus for the generation of radio-active substances conprising an impulse generator, a disoherge tube conneeted in oireuit with sald impulse generator device, sala tube beinc arganged to produce a rast cathode stream, an anti-cathode of a heavy elenont oontaining aubstanee arranged to intercept the eathode strean to produce hard $x \rightarrow$ rays, a bery 1 ifu blcek positioned to be irradiated by the hard rays, and a body of substance to be mado radionaetive loeated ad jeoent the bery11ium blook to intereept the neutron rays therefrom.
46. Apparstue for the generation of radio-setive substances comprising an impulse gonerator, a aparic gap device conneoted in oireuit with said impulse gonerator, a discharge bube oonneeted in eiroust with the impulse genorator and aparic gap deviee, said tube boing arranged to produce a faet oethode strean, an anti-cethode of a heavg element arranged on the pertphery of a wheed, means for rotating the wheol and for introdueing oooling medium thereto, sald wheel boine located so thet a portion of its periphery intercepts sald anthode ray stroaa to produce hard x-rays, a beryilius bloek positioned to be irradated by the hard
4. T-rays, and a body of substance to be sule radio-setive loonted adjacent the berylisum block to intercept the neutron rays thererrom.
47. A mothod of generating a radionsetive elenent from olenents which tranamits in the process into theis own redioactive isotopes, consisting in irradiating a compound of the element which aompound will not interehange the embined atoms of the eloment for the isotopic atoms of the sene elament freed from the compound in the process.
43. A nethod of generating a radiometive elenent from elements whoh transmute in the proeess into their own redionetive isotopes, consleting in irradiating pith neutrons a oompound of the eloment whioh eompound will not interchange the combined atoms of the element for the isotopio atoms of the same elenent freed from the coapound in the proeess.
49. A method of generating, a racilo-setive element from elawents which trensaute in the prooess into their own radioactive isotopes, consieting in irradiatine a compound in Whieh the element is bound to earbon, wh compound wil2 not interchange the ounbined atoms of the olement for the isotopie atoms of the seme element freod from the compound
in the process.
50. A method of generating a radio-active elowent from elemonts which transuate in the proeess into their own radio-active isotopes, oomprising the steps of projecting fast ions of a light element into a quantity of a light element at rest thereby to produce nautron radiation, and subjecting to such radiation a compound of the element to be made redio-setive, which compound will not Interchange the combined atows of the element for the isotopis atoms of the aame alement froed from the compound in the process.
51. A method of generating a radio-active olement from elewents whioh transmute in the process into their own redio-aetive isotopes, oomprising the steps of produoing a fast electron stream, airecting such strean to fall upon an anti-cethode to produce hard $\mathbb{X}-$ rays, allowing such Z -rays to fall upon a body of an element having a dissociable neutron thersby to produee neutron rallation therefrom and subjecting to such neutron radiation a coapound of the elesent to be nade ralio-active, which compound will not interchange the corbined atoms of the dement for the isotopis atoms of the some element freed from the compound in the process.


