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Received documents purporting to be the Application and Provisional Specification of L. Szilard

which have been numbered and dated as above,

M. F. LINDLEY,
Comptroller-General.

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Artificial Transmutation of matter, —

Artificial Transmutation of Matter.

The invention relates to processes and to apparatus adapted for power production, the storage of power through the generation of radio-active bodies, and the generation of radio-active bodies in general.

Radio-active bodies can be generated by bombarding certain elements with neutrons from a Radon-Beryllium (γ Ray) source. The process involved is of different type in different elements. Some elements transmute when bombarded by such neutrons into a radio-active element which has an atomic number lower than the original element. We conclude that such a transmutation is not possible, if heavy elements are bombarded by slow neutrons. We conclude this for the following reason:- if in the primary process which leads to the formation of a radio-active atom, the neutron disappears and a proton or an alpha particle or another positive nucleus is ejected, we get a radio-active atom, the chemical properties of which are different from the original atom as the atomic number of the new element is lower. We predict that such a process will not take place if the energy of the neutron and the atomic number of the bombarded element are such that the positive particles which were to be ejected could not penetrate against the Coulomb field in the inverse process. Therefore we predict that if we induced radio-activity by slow neutrons, (as for instance the neutrons generated by the bombardment of Diplogen by Diplogen canal rays of less than a million volt energy) in heavy elements in absorbed, the new element will have ~~the same~~ no lower atomic number ~~as~~ than the original element. Such induced activity in some heavy elements with slow neutrons have been observed to be ~~efficient~~ processes of good efficiency. As a change in atomic number does not occur we conclude that there is a

in the known cases

change in the mass number of the bombarded element, and we predict that the change consists not in a decrease but in an increase of the mass number. We can further predict that a radiation subsequently called sygma radiation is emitted by such elements (i.e. by elements which show no chemical change, but show an induced activity having the same chemical properties as the original element when bombarded by neutrons as for instance, Iodine, Arsenic, [illegible], Silver, [illegible], Rhodium, [illegible], Iridium etc.) when bombarded by neutrons. This sygma radiation carries away the excess energy liberated in the process of the capture of the bombarding neutron. ~~Next~~ fraction of this sygma radiation consists of "hard X-rays," but we wish to leave it open what portion of the sygma radiation consists of "hard X-rays" and this fraction might vary from element to element. We further predict that the sygma radiation can liberate neutrons from certain elements ~~and also "hard X-rays" can do so.~~ Further a similar action can be exercised by fast electrons in processes in which the fast electron is not captured. ~~Sygma radiation, "hard X-rays" and fast electrons can generate radio-active bodies direct by disintegrating elements while ejecting charged or uncharged particles.~~ They can further produce radio-active bodies indirect (and this is most important) by ejecting from an element a ~~"peculiar radiation", for instance~~ neutrons which generate radio-active bodies in the same element or in another element mixed with the first element, or exposed to the radiation of the first element.

Radio-active bodies can be generated according to this invention by the action of fast electrons or the action of ~~the penetrating radiation (containing~~ hard X-rays ~~is~~ are emitted by matter if fast electrons fall on matter (especially if they fall on heavy elements like Bi, Pb, Hg, Th, U). in several different ways.

~~We shall refer subsequently to this penetrating radiation as "hard X-rays" without wishing to assert that no other radiation is present or active in the processes induced by the "X-rays".~~

~~1.~~ Certain elements transmute into radio-active bodies under the influence of the said "hard X-rays" or fast electrons when in a pure state (not mixed with other elements). This action on a pure element can be of two different types.

A). The "hard X-rays" can disintegrate the element for instance by ejecting a proton, or an alpha particle or a neutron, leaving an unstable element which transmutes spontaneously.

B). The said "hard X-rays" generate ~~a peculiar radiation~~ of the element for instance neutrons which re-act with the element itself and transmutes it into a radio-active body. (The neutron may be ejected by the "hard X-rays" from one atom and be absorbed by another atom of the element). Whether this type of action is present can be seen by investigating the action of the said "hard X-rays" on thin sheets of the element; thin sheets will show no effect of this type B).

~~2.~~ Certain "mixtures" of two or more elements will show an action of the X-rays or a cathode ray of the following type:- ~~a peculiar radiation~~ neutrons will be emitted by one of the components of the mixture under the influence of the "hard X-rays". ~~(this peculiar radiation can for instance consist of neutrons)~~ and another component of the mixture will transmute into a radio-active body under the influence of the said ~~peculiar~~ neutron radiation ~~(neutrons)~~.

Especially favourable are combinations of an element like Beryllium or Diplogen which yield neutrons under the influence of "hard X-rays" with ~~an~~ other elements, especially with such elements which shows an induced activity when bombarded by neutrons without showing a chemical change in the process. (Such elements can be selected either by radiating the elements mentioned ~~on page 5~~ above one by one with a Radon-Beryllium neutron source and investigating the chemical properties of the induced activity or alternatively by radiating the elements one by one with slow neutrons and

selecting those elements which show an induced activity under the influence of slow neutrons. (Slow neutrons can for the purpose of this investigation by generated by bombarding Fluorine with a Beryllium-Radon α-Ray source or by bombarding Diplogen with Diplogen canal rays). Some of the elements like Phosphorous, Silver, Iodine, Arsenic, Uranium, Bromine, Manganese, Iridium, Rhodium etc. which transmute into radio-active bodies when radiated by "hard X-rays", while being mixed with Diplogen can be also transmuted into radio-active bodies according to the process indicated in 1B.

In order to utilise fully the "hard X-rays" one has to surround the anti-cathode by a thick wall of the element or of the mixture of elements which we wish to irradiate, so that a sufficiently large fraction of the "hard X-rays" should get absorbed.

Instead of exposing the above mentioned elements or combination of elements to the "hard X-rays" we can expose them direct to the action of the fast electrons.

As fast electrons produce hard X-rays it is difficult to differentiate between their own actions and the action of the hard X-rays, and therefore, we have used in this application the word 'hard X-rays' both for hard X-rays and fast electrons without differentiating between them. We wish it therefore to be understood that whenever hard X-rays are mentioned in this application we have included both X-rays and electrons without differentiating between them If we produce radioactive bodies by irradiating one of those elements which, like Iodine, transmute into their own radioactive isotope, it requires a special method chemically to separate the radioactive element from its irradiated isotope. According to the invention we can achieve such a separation by irradiating a chemical compound of the said elements.

Those atoms of our element which transmute into a radioactive atom are thrown our of the compound and will subsequently be called 'free'. If we choose a compound which in the circumstances does not interchange the atoms of our element bound with the compound with the 'free' atoms which are their isotope, we can chemically separate the 'free' atoms from the compound and thereby separate the radioactive isotope from the irradiated element. Compounds in which the element in which we are interested are bound direct to carbon are very often suitable. For instance in the case of iodine compounds like iodoform or ethyl iodide can be irradiated and after irradiation the radio-active isotope can be concentrated by separating the 'free' iodine from the iodoform or the ethyl iodide. In order to protect radioactive iodine a small amount of ordinary iodine can be dissolved in the organic iodine compound before irradiation or after irradiation but before separation.

This principal of isotopic separation can also be applied if the element transmutes into a radioactive element which is chemically different from the bombarded element. Though in this case there is no inherent difficulty of chemically separating the radioactive element it may be convenient in certain cases to proceed as if the radioactive and bombarded element were isotopes.

~~Essential features of the invention are:~~

~~1.~~ The production of radioactive bodies by fast electrons or X-rays jointly called 'hard X-rays', according to processes described on page 4, under point 1a and b and point 2, and the chemical separation of the radioactive element from its irradiated isotope. Examples for such isotopic transmutation are for instance bromine, iodine, arsenic and iridium and gold.

We wish now to describe chain reactions which permit to get an increased output of radioactive bodies and produce and store energy on a large scale. The links of the chains which we wish to discuss are formed by at least two different

Figure 1 shows an arrangement suitable for the production of fast electrons and "hard X-rays". 1 is the primary of a transformer, the secondary 2 or which is connected to the points 3 and 4. 3 is connected to the cathode 8 of the rectifier tube 5 and to the anode 7 of the rectifier tube 6. Point 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 the earth. The anodes 15 and 16 are connected to point 17, and this point is 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 condensors 21, resistances 22 and spark gaps 23.

This impulse generator is adapted to produce intermittant voltage up to 10 million volts, transmitted to the discharge tube 24 through the spark gap 25. 26 is the cathode of the discharge tube, the anode 27 of which is connected to the earth. The fast electrons emerge through the metal window 27 (which is the anode as well) and are hitting a body 28. This body is used as an anticathode and yields "hard X-rays" with very good efficiency if it is built of Bi, Pb or some other heavy element. If the anticathode is surrounded by a thick sheet containing a mixture of the elements

Li, Be, B, N, F, Na, Mg, Al, Si, P. S, Cl, K, V, Cr, Mn, Fe, Co, Ni, Zn, As, Se, Br, Rb, Sr, Zr, Mo, Rh, Pd, Ag, Cd, Sn, Sb, Te, Cs, Ba, Hf, Ta, W, Ir, Pt, Au, Hg, Tl, Pb, Bi, Th, U

radio-active bodies are generated in this sheet.

The generation of radio-active bodies is due to different types of action, mentioned on page 4

A particularly efficient way of producing radioactive bodies by using high voltage electron-tubes, is based on the method described ~~in point 2 on page 4~~ above. A very efficient combination is to use beryllium as one component and another element, for instance iodine or arsenic or some other suitable element as the second component. It is of course not necessary actually to mix the two elements but only to expose the second element to the radiation ~~and meet it~~ which is emitted by the beryllium under the influence of the excitation of the beryllium by the X-rays or fast electrons produced by the high voltage electron tubes.

In Figure 2, 27 is the window of the high voltage tube through which the fast electrons are ejected. The electrons hit the rotating anticathode 30 which is covered with lead or tungsten (W) 31. This anticathode is water-cooled, the water entering the rotating body through the axis 35, 32 is a beryllium block in which a space has been left for the rotating anticathode and for the path of the cathode rays 33 between the window 27 and the anticathode. This beryllium block may for instance have a size of 25 cm. x 25 cm x 25 cm. The voltage used to operate the electron tube may be three million volt. The beryllium block is surrounded by a block 34 of the element which we wish to transmute into a radioactive element, for instance, iodine, or arsenic or any other element that is suitable. While it is advisable to use metalic beryllium in the block 32 the element in the block 34 may be present in the form of an organic compound in order to make an isotopic separation possible after irradiation. The dimensions of block 34 may for instance be 50 cm x 50 cm x 50 cm.

If heavy hydrogen or compounds of heavy hydrogen like lithium hydride or heavy water are used instead of beryllium it is advisable to use higher tensions for the generation of the X-rays in order to get a high efficiency.

Since the output is within certain limits proportionate to the thickness of material which the X-rays have to travel in beryllium, and also to the thickness of material which the rays emitted by the beryllium have to travel in the material in which we wish to induce radioactivity it is essential to choose the dimensions both of the beryllium and of the material which we wish to activate. If we have only a limited amount of the material which we wish to activate (limited from the point of view of keeping down the capital investment and the waste of material which accompanies the chemical separation of the radioactive material) it may be advisable to reverse the arrangement shown in Figure 2 in the following way: 34 the outer block should be made of beryllium and 32 the inner block should be made of the material which we wish to activate.

Fast electrons have a similar action on beryllium as hard X-rays, a fraction of this action may be due to the generation of hard X-rays in the beryllium but another fraction may be due to the direct action of the fast electrons on the beryllium. In view of the fact that hard X-rays generat fast electrons in the beryllium, part of their action may be due to fast electrons. In any case we do not wish to differentiate here between the action of fast electrons and hard X-rays, and while we think it likely that the direct action of hard X-rays on the beryllium plays the major part in the liberation of neutrons we wish to envisage the following modification of our method: the electrons of the discharge tube fall instead of lead on beryllium can be put into the place of the rotating anticathode instead of the lead coating 31.

of the rotating anticathode 30 in Figure 2.

The material which we wish to activate is not used up appreciably. For instance if we irradiate ethyl iodide with neutrons and separate the active iodine by removing it from the ethyl iodide through shaking the ethyl iodide with water in the presence of a reducing agent we can prevent the ethyl iodide from being mixed with the water and easily separate the water containing the active iodine from the ethyl iodide.

After separating the radioactive element one can build up chemical compounds especially organic compounds from it.

Essential features of the invention are the generation of radioactive bodies by means of high voltage electron tubes and the chemical separation of the radioactive element based on the irradiation of the chemical compound of the element which does not exchange the atoms of this element within the compound against the atoms of the same element outside the compound. A further essential feature is the combination of an X-ray tube with beryllium and a second element which will transmute into a radioactive element under the influence of the rays emitted by beryllium which is exposed to the X-rays.

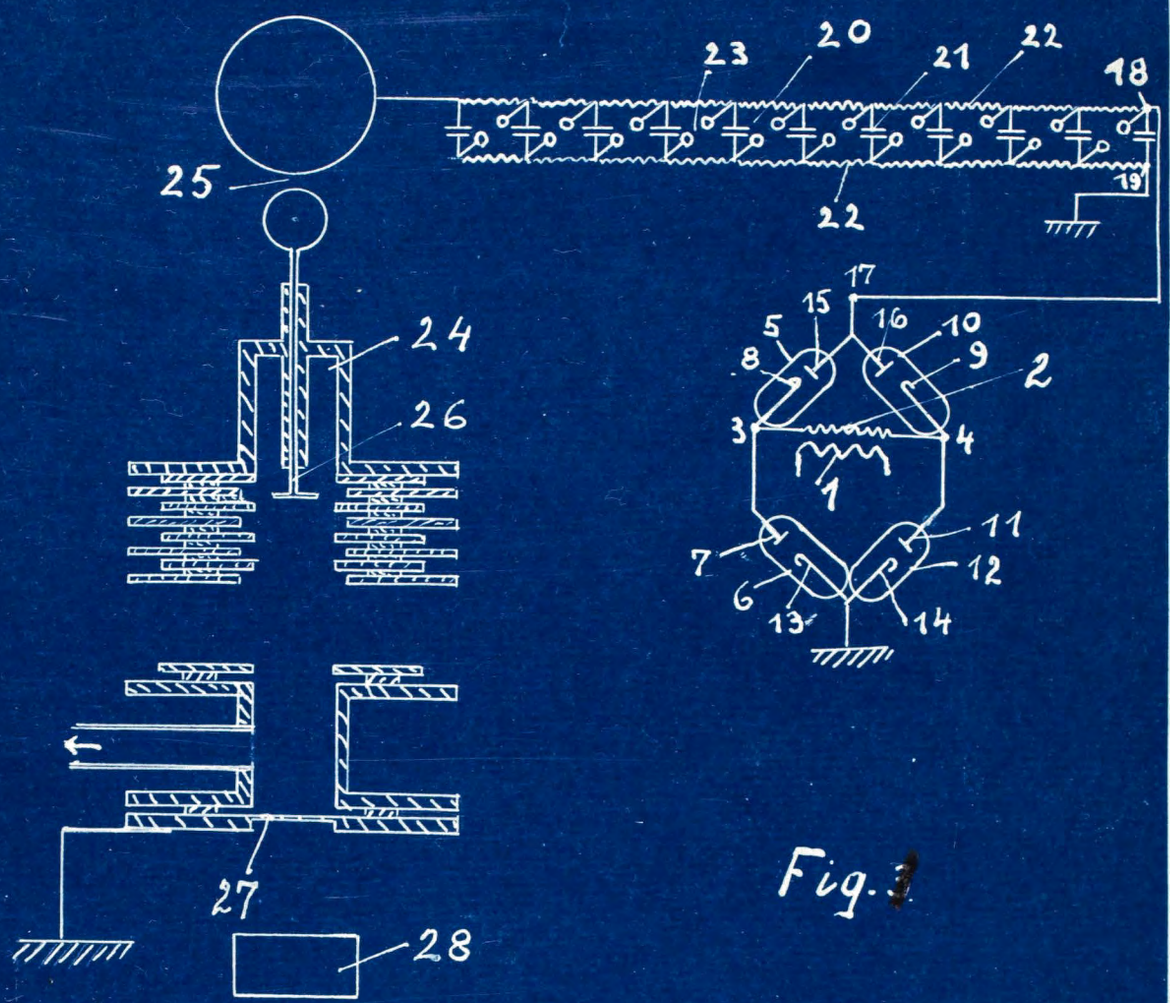

Fig. 1

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