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Telegraphic Address: PATENT OFFICE, LONDON.
Telephone No.: HOLBORN 8721.

THE PATENT OFFICE,
25, SOUTHAMPTON BUILDINGS,
LONDON, W.C.2.

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The Comptroller has to inform you that the desired extension of time for one month for leaving a Complete Specification in respect of the application for a Patent, numbered and dated as above, has been allowed.

Under this extension the Complete Specification must be left within ten months *from the date of the application for a Patent.*

No further extension is obtainable.

To G. A. H. Marriott Esq.

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B-4

Transmutation of chemical elements

The invention concerns methods and apparatus for the production of nuclear transmutation leading to the generation of radio-active bodies, to the storage of energy by means of the generation of radio-active bodies and the utilisation of the energy which has thus been stored for the production of heat and power, further to the liberation of nuclear energy and the utilisation of the liberated energy.

1) Generation of radioa-active bodies . It is not new to produce elements capable of spontaneous transmutation by bombarding certain elements with fast charged nuclei,for instance by bombarding carbon with protons or aluminium,bor and magnesium with helium ions (particles). However, the radio-active elements produced by the bombardment of these light elements with protons or alpha particles, have a short existance (they disintegrate spontaneously in a time shorter than a few hours to half their amount), and it is not possible to use these charged nuclei for the transmutation of the heavier elements withngood efficiency as the ionisation loss gets too large. It is, however, possible to produce with good efficiency(both from light and heavy elements) radio active substances a quantity of which decomposes to one half of the original amount in a period of time exceeding 24 hours, if a thick layer of substance is exposed to a penetrating radiation which is emitted when collisions between heavy hydrogen (diplogen) [illegible] (or nuclei) and light elements,including heavy hydrogen (diplogen so called deuterium) itself, are produced.

Fig 1 shows an example of a suitable arrangement. 11 is an electrical discharge tube ejecting a beam 12 of fast diplogen ions. The ions fall on a substance 13 consisting of for instance gasous diplogen or a diplogen compound or lithium, causing transmutation, i.e. a nuclear reaction of the diplogen ion with an atom of the target. The sub - stance 13 is surrounded by a layer 14 containing the element which we wish to transmute into a radio-active element. In order to have a good efficiency,the thickness of the layer 14 has to be sufficiently large,

compared with the mean free path of the neutron, for this transmutation.

Fig 2. shows the electrical discharge tube referred to in fig. 1. It is a high voltage positive ray tube. There is an auxiliary positive ray tube on top of the high voltage tube. 11 is the anode, 15 the cathode of this auxiliary tube. Diplogen is admitted through the tube 13 and pumped away through 14.

The transmutation of elements into radio active bodies under the influence of neutrons can be demonstrated even before one knows which elements will transmute into radio active bodies, if one prepares a mixture of all suitable elements ~~leaving~~ leaving out the radio active elements, but including Uranium and Thorium (from which the beta active products have been removed) and exposes this mixture to a neutron radiation. The mixture shows after exposure radioactivity decaying with a large number of half-life periods the relative intensity of which depends on the composition of the mixture and on the time of irradiation.

These are the essential features of the method for the production of radio active substances which are disintegrating slowly:
Light elements are bombarded by each other, especially diplogen is brought into collision with other light elements or with diplogen itself. Uncharged particles of a mass of the order of magnitude of the mass of a proton are emitted as a consequence of the collisions between nuclei of light elements. Such uncharged nuclei penetrate even substances containing the heavier elements without ionization losses and cause the formation of radio active substances in a layer which is exposed to them with good efficiency if the thickness of the layer is of the order of magnitude of ~~1 metre~~ the mean free path of the neutron. We have therefore two steps of good efficiency in series: the production of uncharged nuclei by collision between light elements (the ionization losses are small because the elements have a small atomic number and therefore a small nuclear charge and a small number of electrons per atom) and the production of radio active substances by means of the uncharged nuclei (the ionization losses are practically absent even in case of passage through heavy elements.)

The method described hitherto was characterized by shooting a particle through matter which is at rest. As described, a diplon (a diplogen nucleus) shot into diplogen at rest will in a large proportion of cases lose its energy by ionizing the diplogen and cause no transmutation in those cases.

If we were to maintain a very large concentration of energy in a space filled with atoms of such elements which will suffer transmutations, if the atom (nuclei) strike each other at that temperature (which corresponds to the energy concentration maintained) then the following would hold good: the energy transmitted to the electrons by the moving nuclei would be continuously retransmitted to the nuclei. It is sufficient to maintain a suitable energy concentration for a fraction of a second. On can do so by shooting charged particles which have been accelerated in an electrical discharge tube through a space in which diplogen alone, or lithium hydrid (or other compounds of hydrogen and lithium) or other combinations of hydrogen or diplogen with a third light element are present. If we use an electric condensor (and discharge it) in a fraction of a second across the discharge tube we can introduce (especially if we use several discharge tubes which are operated simultaneously) a very large energy in a very short period of time into the "transmutation space" filled, e.g. with diplogen. As "heating rays" we can use protons or heavier ions, or we can use cathode rays. We can easily estimate how much energy must be stored in the electric condensor in order to have sufficient supply of energy to heat up 1 cubic cm of diplogen.

If nuclear reaction of diplogen with itself is enforced through heating up diplogen with an electric discharge, a neutron radiation is emitted which can be used for the generation of radio active bodies as described above. This method is described in the following:

In Figure 6, 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. 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 radio-active 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.

Fast electrons have a similar action on beryllium as hard x-rays, a fraction of this action may be due to the direct action of the fast electrons on the beryllium. In view of the fact that hard x-rays generate fast electrons in the beryllium, part of their action can 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 direction 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 which can be put into the place of the lead casting 31 of the rotating anticathode 30 in Figure 6.

Many elements transmute when bombarded by slow neutrons into their own radio-active isotope and it requires a special method chemically to separate the radio-active element from its irradiated isotope. We can achieve such a separation by irradiating a suitable chemical compound of the said element. Those atoms of our element which transmute into a radioactive atom are thrown out 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 within the compound with the "free" atoms which are their isotopes 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 radio-active iodine a small amount of ordinary iodine can be dissolved in the organic iodine compound before irradiation or after irradiation but before separation.

In the following we shall deal with methods and apparatus for the production of energy and generation of radio-active bodies by means of chain re-action. In order to maintain such a chain an initial radiation of neutrons is generated by one of the methods described further above. If the neutrons enter a space which has the proper shape and size and which is filled with a proper combination of elements their energy or the number, or both, can be increased through their interaction with the substance which fills the chain reaction space. The interaction of a neutron with matter can lead to the liberation of further neutrons - these newly liberated neutrons liberate again in their turn further neutrons so that we can have a chain reaction in which a large number of neutrons are liberated, the total number of which is determined by the geometry of the arrangement.

Figure 7 and 8 show such a chain reaction apparatus. A neutron radiation, the initial radiation, is generated by the high voltage canal ray tube 1 (shown in greater detail in figure 2.) This tube generates fast deutons which strike the target 28 which contains deuterium. The neutron radiation emerging from 28 acts on the matter 3 which fills the spherical transmutation space. The composition of this matter 3 will be discussed further below and is such that a chain reaction is released by the neutrons. The pumps 120, 121 and 122 pump a liquid for instance water or mercury through the pipe systems 107, 110, 111 thereby cooling the transmutation area 3 and driving the heated liquid through the boiler 126. The boiler supplies steam to a power plant. The neutrons emerging from the sphere 3 act on a layer 9 which is composed of an element that will transmute into a radio-active body which is suitable for the storage of energy.)

An essentially different way of introducing the initial radiation into the chain reaction chamber is the

arrangement shown in Figure 9. 401 is the cathode ray tube described in Figure 1. 402 is a sheet of a heavy element for instance Pb, or U in which penetrating radiation (hard X-rays) is generated with an extremely good efficiency if the electrons have a voltage about or over one million volt. This efficiency increases very rapidly with the voltage, and is much higher than it could be expected from the experience based on ordinary x-ray work. The thickness of the sheet 402 is such as to enable the generated penetrating radiation to penetrate through this sheet and act on the transmutation chamber 106 (in Figure 8). Nevertheless the sheet can be sufficiently thick to utilise more than half of the energy of the cathode rays. The X-rays emerging from sheet 402 penetrate the layer 3 and can liberate ~~efficient particles~~ neutrons either from the layer 3 or from a substance 407 placed in the interior of the layer 3.) For instance, if we have ~~diplogen~~ beryllium present in 403 or in 3, neutrons will be ~~present~~ liberated by X-rays. These neutrons can then maintain a chain reaction as discussed further above and further below. The advantage of using X-rays as an initial radiation is the following: The x-rays penetrate through a perfectly closed layer 3 into the interior of the layer and therefore a leak of neutrons from the interior can be avoided. This is specially important if we have to deal with a neutron chain in which no multiplicator action is involved. In such cases x-rays may be used with advantage as initial radiation especially in view of the unexpectedly large efficiency of the x-ray production by means of fast electrons acting on heavy elements.

In the simplest case, when neutrons alone form the links of the chain, we shall demonstrate in the following the importance of the shape and the size of the transmutation space. If we have a closed spherical layer of material in which the chain reaction takes place the inner radius (r) of which is large compared with the

Formula corrected later:

mean free path / of the efficient particles which maintain the chain, the density (s) of the neutrons will with good approximation be given as a function of the radius (r) by the following equation:

$$D\, d^2(rs) / dr^2 + A\,(rs) = 0$$

D and A are determined by: the mean free path of the neutrons a; the mean velocity of the neutrons w; the factor of the multiplicating action f which says how many collisions of a neutron

LS X electron are needed in the average in order to produce one neutron

LS X new electron. $A = w / af$; $D = aw / 3$: $\sqrt{\frac{D}{A}} = \frac{a\sqrt{f}}{\sqrt{3}}$

We are interested in the critical thickness ℓ of the

mean free paths of the ~~efficient particles~~ neutrons which maintain the chain, the density (s) of the neutrons will with good approximation be given as a function of the radius (r) by the following equation:

$D \, d(rs) / dr + A(rs) = 0$

D and A are determined by: the mean free path of the neutrons a; the mean velocity of the neutrons w; the factor of the multiplicating action f which says how many collisions of an ~~electron~~ neutron are needed in the average in order to produce one new ~~electron.~~ neutron. $A = w / af$; $D = aw / 3$; $\sqrt{\frac{D}{A}} = \frac{af}{\sqrt{3}}$

We are interested in the critical thickness of the spherical layer for which the gradient of the density S vanishes. If the thickness ($r_2 = r_1$) approaches l_0 we can maintain with a very weak source of initial radiation in the interior of the inner surface of the spherical layer a very strong chain reaction and we can easily get one thousand or more times more neutrons emerging from the chain reaction layer than the number of the neutrons forming the initial radiation. If the outer surface ($r = r_2$) of the spherical layer were to stand free in space the density s would be zero for that surface and the critical value l would be given by $l_0 = \pi/2 \sqrt{D / A}$. If the outer surface is covered by some material, for instance if the transmutation layer is immersed into water or covered by lead the critical value l is reduced. This is due to the back scattering by water or lead and also to the fact that the neutrons are slowed down in the water and their mean free path is thereby reduced.

It is important to prevent neutrons from escaping out of the interior of the inner surface of the spherical layer and also from being absorbed in the interior. If the initial radiation is generated by apparatus placed into the interior of the sphere the material used should be so selected as to lead to a minimum of absorption.

If the thickness is larger than the critical value l we can produce an explosion.

We shall now discuss the composition of the matter in which the chain reaction is to be maintained. We wish to distinguish three main types of chains.

(a) Pure neutron chains, in which the links of the chain are formed by neutrons of the mass number 1 alone. Such chains are only possible in the presence of a metastable element. A metastable element is an element the mass of which (packing fraction) is sufficiently high to allow its disintergration into its parts under liberation of energy. Elements like uranium and thorium are examples of such metastable elements; these two elements reveal their metastable nature by emitting alpha particles. Other elements may be metastable without revealing their nature in this way. Whether an element is metastable or not can be determined by means of the mass spectrograph. If, for instance, the value obtained by Bainbridge for beryllium by means of the mass spectrograph which appears to be generally accepted at present is really valid, we have to conclude that beryllium is a metastable element and can disintergrate into parts with the liberation of energy, one of the parts set free in its disintergration being a neutron.

If we have an element which is metastable but the disintergration of which is inhibited and if this inhibition can be lifted in a collision with a neutron we shall call such an element an inhibited metastable element. If an inhibited metastable element "A" is exposed to neutrons, we may have the following reaction.

"A" + n = "B" + n + Energy

The element "A" transmutes into an element "B" which has the same atomic number and mass number and energy is transmitted to the neutron. The element "B" may break up into an element "C" and a neutron, the element "C" having the same atomic number as "B". The element "C" may or may not break up into further parts. If the interaction of a neutron with the element "A" leads in this way to an increase in the number of neutrons (the newly created neutrons would together with the original neutrons continue to interact with the elements "A" thereby forming the links of a chain reaction.) We shall call element "A" a metastable multiplicator.

All particles which have a mass number approximately equal to the mass of the proton or a multiple thereof can play a similar role as the neutrons provided they carry no charge or a negative charge and we shall call allthese particles heavy non-positive particles. Protons,deutons and other positive particles can not be used as links of chain reactions. All pure chains in which one and the same heavy non-positive particles forms the links of the chain must necessarily make use of inhibited metastable elements. The simplest non-positive heavy particles apart from the neutron are the neutron with the mass number 2 and the negative proton.

(b) Chains in which two different types of heavy non-positive particles alternate. Such chains need not necessarily make use of metastable elements. For instance, an element "D" may be so chosen that when interacting with a neutron (of mass number 1) a double-neutron (a particle with the atomic number 0 and the mass number 2) should arise and when interacting with a double-neutron a neutron should arise, and that these reactions should have a positive energy balance. If such a chain could be maintained in deuterium each link would liberate between 4 to 5 m.e.v.

$$\left.\begin{aligned} H\,(2) + n\,(1) &= n\,(2) + H\,(1) \\ H\,(2) + n\,(2) &= H\,(3) + n\,(1) \end{aligned}\right\} \quad 4.5 \text{ m.e.v.}$$

Such a chain can also be maintained in mixtures of two different elements "E" and "F" which show the reactions:

$$\text{"F (m)"} + n\,(1) = n\,(2) + \text{"G (m - 1)"}$$

$$\text{"E (k)"} + n\,(2) = \text{"I (k 1)"} + n\,(1)$$

We shall call an element "F" which reacts with an heavy non-positive particle and transmutes into an element the mass number of which is one less,a converter element. An element "E" which reacts with a heavy non-positive particle and transmutes into an element the mass number of which is increased by one, reducer element. Most elements which yield protons when bombarded by deutons can be used as reducer elements. Beryllium can act as a converter element. In order to have a chain action in which the number of neutrons increases we must have apart from the converter and the reducer a multiplicator element which either splits up double-neutrons into two neutrons or from which neutrons are liberated in a process in which the interacting non-positive heavy particle is not captured.

"S"- Chain reactions in which a heavy non-positive particle, for instance, a neutron, and a sygma quantum alternate.

Many elements which capture a neutron emit a radiation which carries away the energy liberated in the capture process. While the nature of this radiation is not yet established beyond doubt (a large fraction of it may consist in a gamma radiation) it can be shown from the laws of thermo-dynamic equilibrium that this radiation, which we shall call sygma radiation, can liberate neutrons from elements and the cross section of this process (which is the inverse process of the capture) can be calculated. Some elements emit two sygma quanta if they capture a neutron and can act therefore as multiplicators in a chain reaction. If we have a mixture of elements (even pure elements have to be considered as mixtures of their isotopes) we can choose the components of the mixture so that one element of the components "K" captures neutrons and emits two sygma quanta of the energies E_1 and E_2; another component "L" absorbs the quanta of energy E_1 and emits neutrons which are again captured by "K" and lead again to the emission of sygma quanta; a third component "M" absorbs the quanta of energy E_2 and also emits neutrons which too will be captured by "K".

In order to have a large absorption coefficient for the sygma quanta we ought to choose such elements "L" and "M" which have a resonance for quanta of the energies E_1 and E_2 respectively. Similarly "K" may have resonance for the capture of the neutrons liberated by the sygma radiations from the other components or else the neutrons may be slowed down for instance by elastic collisions in hydrogen and "K" may have resonance for the neutrons which have been slowed down to its resonance level (which may be at zero energy).

One possible combination of the resonance levels is that "K", "L" and "M" have all resonances at zero energy of the neutron ("K" for capture, "L" and "M" for liberation of neutrons) and that E_1 and E_2 are slightly above the binding energies of the neutron in "L" and "M" respectively.

Examples for elements which have a resonance for the capture of neutrons at zero energy are cadmium, mercury and others. Other such elements, like for instance - rhodium, transmute into a radioactive element if they capture a neutron. If a radioactive element is formed one of the two sygma (gamma) quanta may be emitted with a considerable time lag, corresponding to the half life period of the radioactive element.

By maintaining a chain re-action in combination with means for leading away and utilizing the heat set free in the transmutation process energy can be produced and utilized for power production. In the same way, by heating up deuterium by means of an electrical discharge as described in that part of this specification which relates to Figures 3 and 4 in combination with means for leading away and utilizing the heat set free in the transmutation process energy can be produced and utilized for power production.

Having now particularly described & ascertained the nature of my said invention, and in what manner the same is to be performed, I declare that what I claim is:

Claims.

1) Method and apparatus for the generation of radioactive elements, characterized by a neutron radiation, emitted from a space in which a nuclear transmutation process leading to the liberation of neutrons, is maintained, and by the exposure of an element to the said neutron radiation which element transmutes into a radioactive element under the influence of the said neutron radiation.

2) Method and apparatus according to claim 1 characterized by the said nuclear transmutation process leading to the liberation of neutrons being a nuclear reaction ~~xxxxxxx~~ of diplogen (deuterium) with diplogen or other light elements, or other light elements with eachother.

3) Method and apparatus according to claim 2 characterized by the said nuclear reaction between light elements, being maintained through the action of fast light ions, generated by an electrical device, for instance high-voltage canal ray tube, on a target containing light elements; for instance through the action of ~~xxxx~~ diplogen ~~in~~ canal rays on a target containing diplogen.

4) Method and apparatus according to claim 2 characterized by the said nuclear reaction between light elements being ~~enforced~~ by means of heating up suddenly a space which contains diplogen or other light elements through an electrical discharge in which energy, which has been stored, is suddenly released.

5) Method and apparatus according to claim 1 characterized by ~~xhe~~ a nuclear transmutation process leading to the liberation of neutrons being maintained through the action of ~~x~~-rays, generated for instance by means of a high voltage electron tube, on suitable elements, for instance Beryllium.

6) Method and apparatus according to claim 1 characterized by a nuclear transmutation process leading to the liberation of neutrons being maintained through the action of cathode rays, generated for instance by means of a high voltage electron tube, on suitable elements, for instance Beryllium.

7) Method and apparatus for the generation of radioactive elements according to claim 1, characterized by the exposure of an element to the said neutron radiation, which element transmutes into its own radioactive isotope, in the form of a chemical compound, which is adapted for the chemical separation of the radioactive element from its non-radioactive isotope.

8) Methods and apparatus for the production of energy, characterized by a nuclear reaction between light elements being enforced by means of heating up suddenly a space which contains diplogen or other light elements through an electrical discharge in which energy, which has been stored, is suddenly released.

9) Method and apparatus for the production of radioactive elements or energy, characterized by the generation of an initial radiation, for instance a neutron radiation and exposed to this radiation a body, so composed that a chain reaction of neutrons is maintained by the initial radiation.

10) Method and apparatus for the production of radioactive elements according to claim 9, characterized by the exposure of an element, which element transmutes into a radioactive element under the influence of neutrons, to the neutron radiation generated in the said body in which a chain reaction of neutrons is maintained.

11) Method and apparatus for the production of radioactive elements or energy according to claim 9, characterized by the said body being so composed that a chain of heavy non-positive particles is maintained.

12) Method and apparatus for the production of radioactive elements or energy according to claim 9, characterized by the said body containing a converter element, a reducer element, and a multiplicator.

13) Method and apparatus for the production of radioactive elements or energy according to claim 9, characterized by the said body containing Beryllium.

14) Method and apparatus for the production of radioactive elements or energy according to claim 9, characterized by the said body being so composed that a chain reaction in which neutrons and sygma particles alternate, is maintained.

15) Method and apparatus for the production of radioactive elements or energy according to claim 9, characterized by the said body containing an element "K" which emits more than one sygma quanta for each cap - tured neutron and one or more elements "L", "M" ..... which absorb strongly the sygma quanta emitted by "K" and eject neutrons in doing so.

16) Method and apparatus according to claims 9 and 10, characterized by the use of a hydrogen containing substance, for instance water, for scattering the neutrons, for instance by surrounding the whole space in which transmutation takes place, by water.

17). A method of and apparatus for the transmutation of chemical elements substantially as hereinbefore described and illustrated in the accompanying drawings. Dated this day of 1935