Form P. Ack. 4.

B-1

Transmitted to the Examiners

THE PATENT OFFICE,

25, SOUTHAMPTON BUILDINGS,
CHANCERY LANE, LONDON, W.C. 2.

No. 7840

Date 12 MAR 1934

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.

N.B.—Unless a Complete Specification is left on an Application for a Patent within TWELVE MONTHS from the date of application (or with extension fee, 13 months), the Application is deemed to be abandoned. The investigation as to novelty prescribed by the Patents Acts, 1907 and 1932, is made only when a Complete Specification has been left.
The number and date of this Application must be quoted on the Complete Specification and Drawings (if any), as well as in any correspondence relative thereto.

Wt 2952 144 Bks/8/33 Wt & Sons Ltd 431f/1385 4

Provisional Specifications : -

7840/34 Dated 12th March 1934, 13947/34 dated 9th May 1934,
19157/34 dated 28th June 1934, 19721/34 dated 4th July 1934
~~27050/34 dated 20th Septr.1934~~ 27507/34 dated 25th Septr. 1934.

PATENTS & DESIGNS ACTS 1907 to 1932

COMPLETE SPECIFICATION

IMPROVEMENTS IN OR RELATING TO THE TRANSMUTATION OF CHEMICAL ELEMENTS.

I LEO SZILARD, a citizen of Germany, a subject of Hungary, C/o Claremont Haynes & Co. of Vernon House Bloomsbury Square, London, W.C. 1. do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statements:-

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

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, boron and magnesium with helium ions (α particles). However, the radio-active elements produced by the bombardment of these light elements with protons or alpha particles, have mostly a short existence (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 with good efficiency as the ionisation loss gets too large.

According to this invention neutrons are generated in a chain reaction in which neutrons and another particle or quantum which carries no positive charge alternate and energy or radio active bodies or both are generated either in the process of the chain reaction itself or by the radiations arising out of the chain reaction.

I wish to make clear that while I am describing in the present Specification methods and apparatus for the generation of radio-active bodies by means of neutrons this in itself is not claimed and does not form part of the subject matter of this Specification. It forms part of the subject matter and is claimed in my Specification and Application for Letters Patent No. 7840/1934.

few hours to half their amount), and it is not possible to use these charged nuclei for the transmutation of the heavier elements with good efficiency as the ionisation loss gets too large.

According to this invention neutrons are generated in a chain reaction in which neutrons and another particle or quantum which carries no positive charge alternate and energy or radio active bodies or both are generated either in the process of the chain reaction itself or by the radiations arising out of the chain reaction.

It is 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) atoms (or nuclei) and light elements, including heavy hydrogen (diplogen, also called deuterium) itself, are produced.

In the accompanying drawings 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 gaseous 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 substance 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 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 radio activity 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 some features of one method for the production of radio active substances which disentegrate slowly by means of neutrons. 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 (neutrons) are emitted as a consequence of the collisions between nuclei of light elements. Such uncharged nuclei penetrate even substances containing the heavier elements without ionisation 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 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) liberated in a nuclear reaction between light elements. The nuclear reactions between the light elements were brought about either by the bombardment of a target containing light elements with a beam of fast light atoms.

Another new method for the generation of radio active bodies is based on the fact that X rays and also fast electrons can liberate neutrons from certain elements, for instance from beryllium. This is described in connection with Fig. 5 and Fig. 6.

Fig. 5 shows an arrangement suitable for the production of hard X-rays, in which 1 is the primary of a transformer, the secondary 2 of 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 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 condensers 21, resistances 22 and spark gaps 23.

This impulse generator is adapted to produce intermittent voltage up to 10 million volts, transmitted to thedischarge tube 24 through the spark gap 25, 26 is the cathode of the discharge tube, the anode 27 of which is connected to earth. The fast electrons emerge through the metal window 27 (which is the anode as well) and hit 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.

The generation of radio active bodies by means of neutrons which have been liberated from some suitable element by

X-rays is shown in Fig. 6. In Fig. 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. 52 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 25cm x 25cm. The voltage used to operate the electron tube may be three million volts. 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 metallic beryllium in the block 52 the element in the block 34 may be present in the form of a suitable chemical compound in order to make an isotopic separation possible after irradiation. The dimensions of block 34 may, for instance, be 50cm x 50cm. x 50cm.

In the following I shall deal with methods and apparatus for the production of energy and generation of radio-active bodies by means of chain reactions. In order to maintain such a chain an initial radiation of neutrons is generated by one of the methods described 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 their 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 netrons liberate again in their turn further neutrons so that one 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.

Figs. 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, Fig. 7 (shown in greater detail in Fig. 2) This tube generates fast deuterons 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, Fig. 8 pump a liquid for instance water or mercury through the pipe systems 107, 110, 111, Figs. 7 and 8 thereby cooling the transmutation area 3, Fig 7., and driving the heated liquid through the boiler 126, Fig. 8. The boiler may supply steam to a power plant. The neutrons emerging from the sphere 3 act on a layer 9, Fig. 7 which is composed of an element that will transmute into a radio-active body.

An essentially different way of introducing the initial radiation into the chain reaction chamber is the arrangement shown in Fig. 9. 1 is the cathode ray tube shown in Fig. 5. 402 is a sheet of 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 volts. 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 consisting of the layers 407 and 3 (for the cooling of this chamber and the utilisation of the heat generated in it I refer to Fig. 8, 106 in Fig. 9 is to be identified with 106 in Fig.8!). Nevertheless the sheet can be sufficiently thick to utilize

more than half the energy of the cathode rays. The X-rays emerging from sheet 402 penetrate the layer 3 and can liberate neutrons either from the layer 3 or from a substance 407 placed in the interior of the layer 3. For instance, if beryllium is present in 407 or in 3, neutrons will be 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.

I shall demonstrate in the following the importance of the shape and the size of the transmutation space. I assume that the chain reaction takes place in a closed spherical layer of material the inner radius (r_1) of which is large compared with the mean free path (a) of the neutrons (or other particles which are also involved in maintaining the chain). In this simple case the density (s) of the neutrons will with good approximation be given as a function of the radius (r) by the following equation:

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

D and A are determined by: the mean free path (a) of the neutrons; the mean velocity of the neutrons w; the factor of the multiplicating action f which says how many collisions of a neutron are needed in the average in order to produce one new neutron.

$A = w/af$; $D = aw/3$; $\sqrt{D/A} = \frac{a\sqrt{f}}{\sqrt{3}}$

I am interested in the critical thickness of the spherical layer for which the gradient of the density s vanishes for the internal radius (r_1). If the thickness of the spherical layer ($r_2 - r_1$) (r_2 and r_1 are the external and internal radii respectively) approaches a certain critical

thickness L one 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 one 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 $L = \pi/2\sqrt{D/A}$. 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 of the layer is larger than the critical thickness L the number of neutrons would go on increasing indefinitely and such an increase is only stopped when the heat which is liberated in the process causes the spherical layer to explode.

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

(a) Chains in which two different types of heavy non-positive particles alternate (Heavy non-positive particles are particles which have a mass roughly equal to the mass of the proton or a multiple thereof and which carry no positive charge. The neutron is one such particle and I have reason to believe

that other heavier particles than the neutron exist which carry no charge.) For instance, an element "D" may be so chosen that when interacting with a neutron (of mass number 1) a multiple neutron (a particle with the atomic number 0 and a mass number higher than 1) should arise and when interacting with a multiple neutron a simple neutron should arise, and that these reactions should in toto have a positive energy balance. Or alternatively a mixture of two elements "E" and "F" can be so chosen that element "F" (the converter element) when it reacts with a simple neutron should transmute into an element the mass number of which is lower and generate a multiple neutron; on the other hand element "E" (the reducer element) should when it reacts with a multiple neutron transmute into an element the mass number of which is increased and generate a simple neutron. In order to have a chain reaction in which the number of neutrons increases it is necessary that apart from the converter and the reducer element there should be present a multiplicator element from which neutrons are liberated by neutrons in a process in which the interacting neutron is not captured (or alternatively a multiplicator element which splits up multiple neutrons).

(b) 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 I 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 one has a mixture of elements (even pure elements have to be

considered as mixtures of their isotopes) one can choose the components of the mixture so that one of the components "K" captures neutrons and emits two sygma quanta of the energies E_1 and E_2; another compoent "L" absorbs the quanta of energy E_1 and emits enutrons 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 one 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.

Examplesfor elements which have a resonance for the capture of neutrons at zero energy are cadmium, mercury and the like. Other such elements, like for instance, rhodium, transmute into a radio active element if they capture a neutron. If a radio active 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 radio active element.

By maintaining chain reaction 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 and ascertained the nature of my said invention, and in what manner the same is to be performed, I declare that what I claim is:-

1. A method ~~or apparatus~~ for the generation of neutrons, the generated neutrons generating radio active elements or energy or both, characterized by the maintenance of a chain reaction in which neutrons and another particle or quantum which carries no positive charge alternate.

2. A method ~~or apparatus~~ according to Claim 1 characterized by the generation of an initial radiation which can be a neutron radiation, and exposed to this initial radiation a body so composed that a chain reaction is ~~maintained~~ caused by the initial radiation.

3. A method ~~or apparatus~~ according to Claim 2 characterized by the said body being so composed that a chain of heavy non-positive particles the mass of which is roughly equal to the mass of the proton or a multiple thereof is set up.

4. A method ~~or apparatus~~ according to Claim 3 characterized by the said body containing a converter element, a reducer element, and a multiplicator.

5. A method ~~or apparatus~~ according to Claim 2 characterized by the said body containing Beryllium.

6. A method ~~or apparatus~~ according to Claim 2 characterized by the said body being so composed that ~~the~~ a chain reaction sets in in which neutrons and sygma particles alternate.

7. A method ~~or apparatus~~ according to Claim 6 characterized by the said body containing an element "K" which emits more than one sygma quanta for each captured neutron and one or more elements "L", "M" ..... which absorb strongly the sygma quanta emitted by "K" and eject neutrons in doing so.

8. A method according to Claim 2 characterized by the exposure of an element to the radiations generated in the said body which element transmutes into a radio active element under the influence of the said radiations.

9. A method according to Claim 2 or 8 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.

10. Improvements in or relating to the transmutation of chemical elements substantially as hereinbefore described and illustrated in the accompanying drawings.

11. An apparatus for carrying out the methods claimed in any of the Claims 1 to 9.

Dated the 9th day of April 1935.

Claremont Haynes & Co

Vernon House, Sicilian Avenue,
Bloomsbury Square, W.C.

Applicants Solicitors.

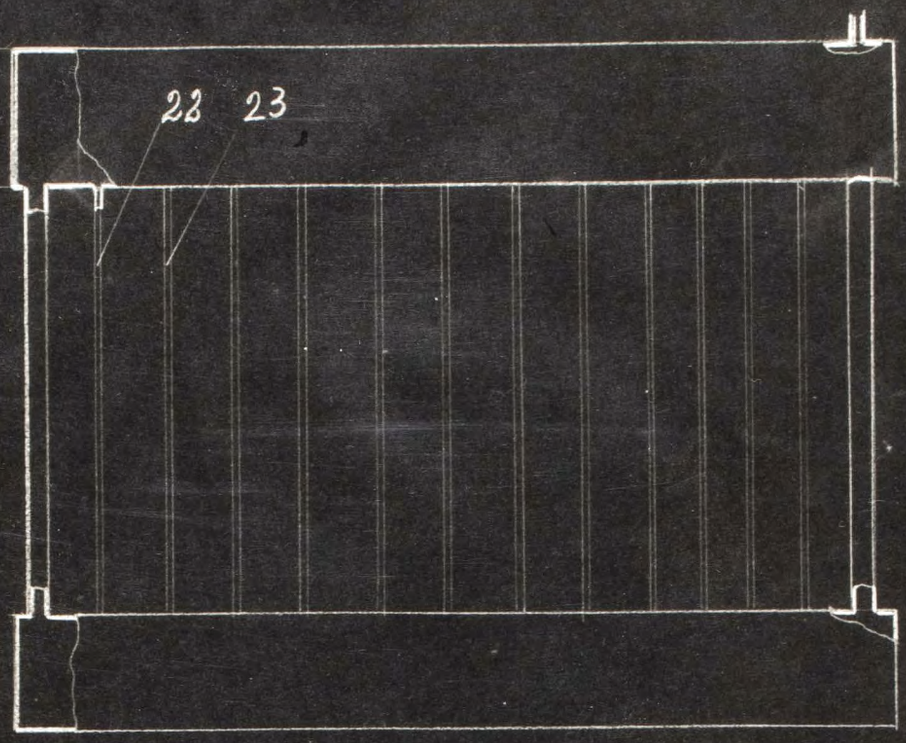


Fig 2a

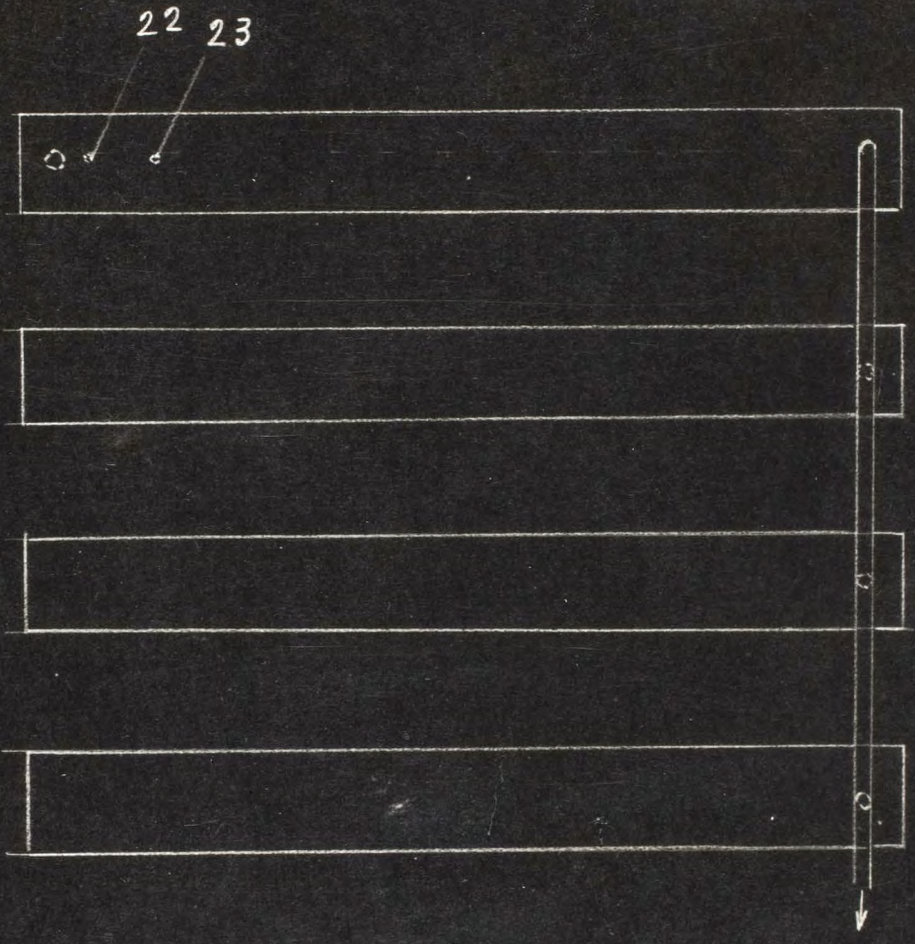


Fig 2b

R March

~~Feb 26~~

20, 26

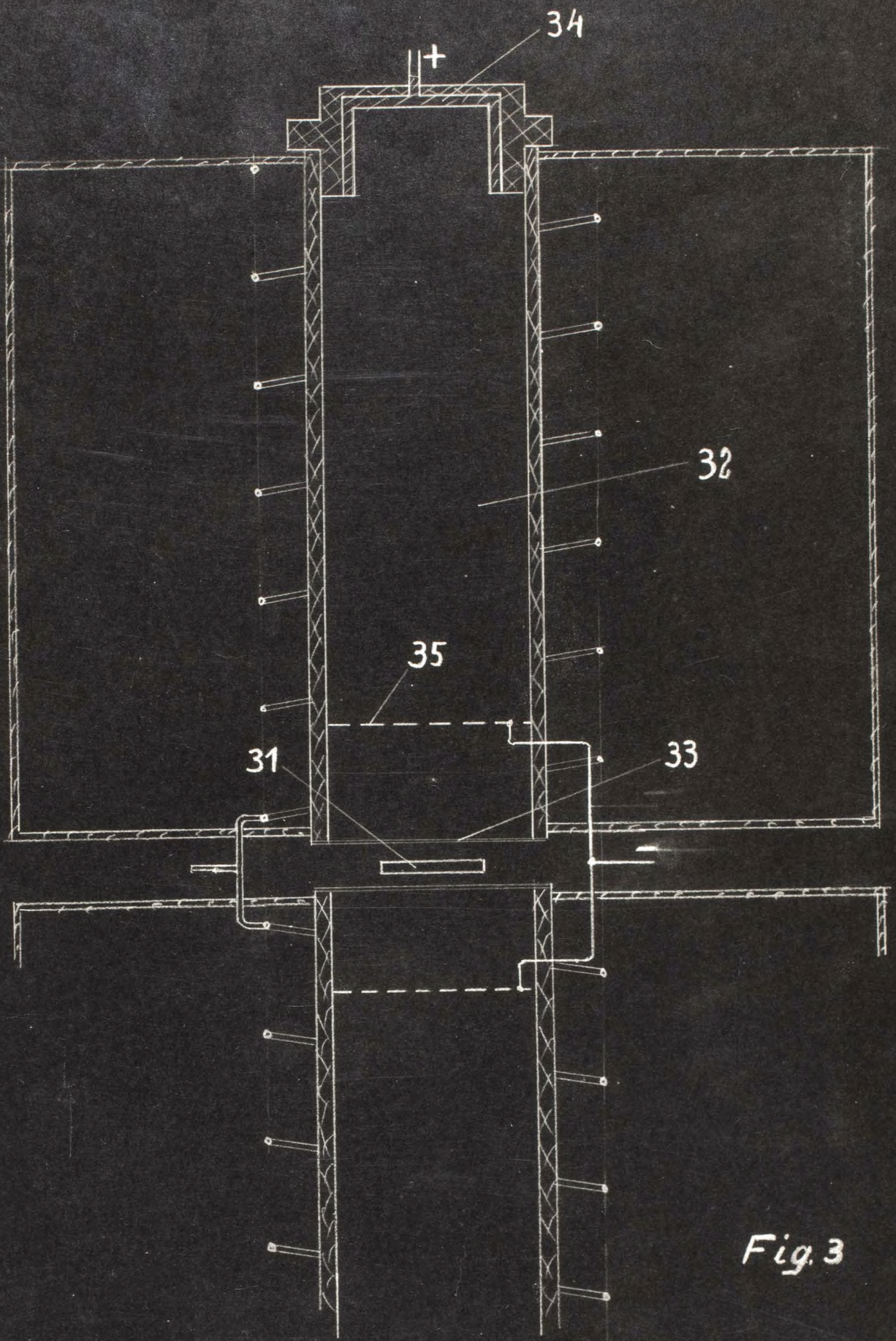


Fig. 3

12 March

3

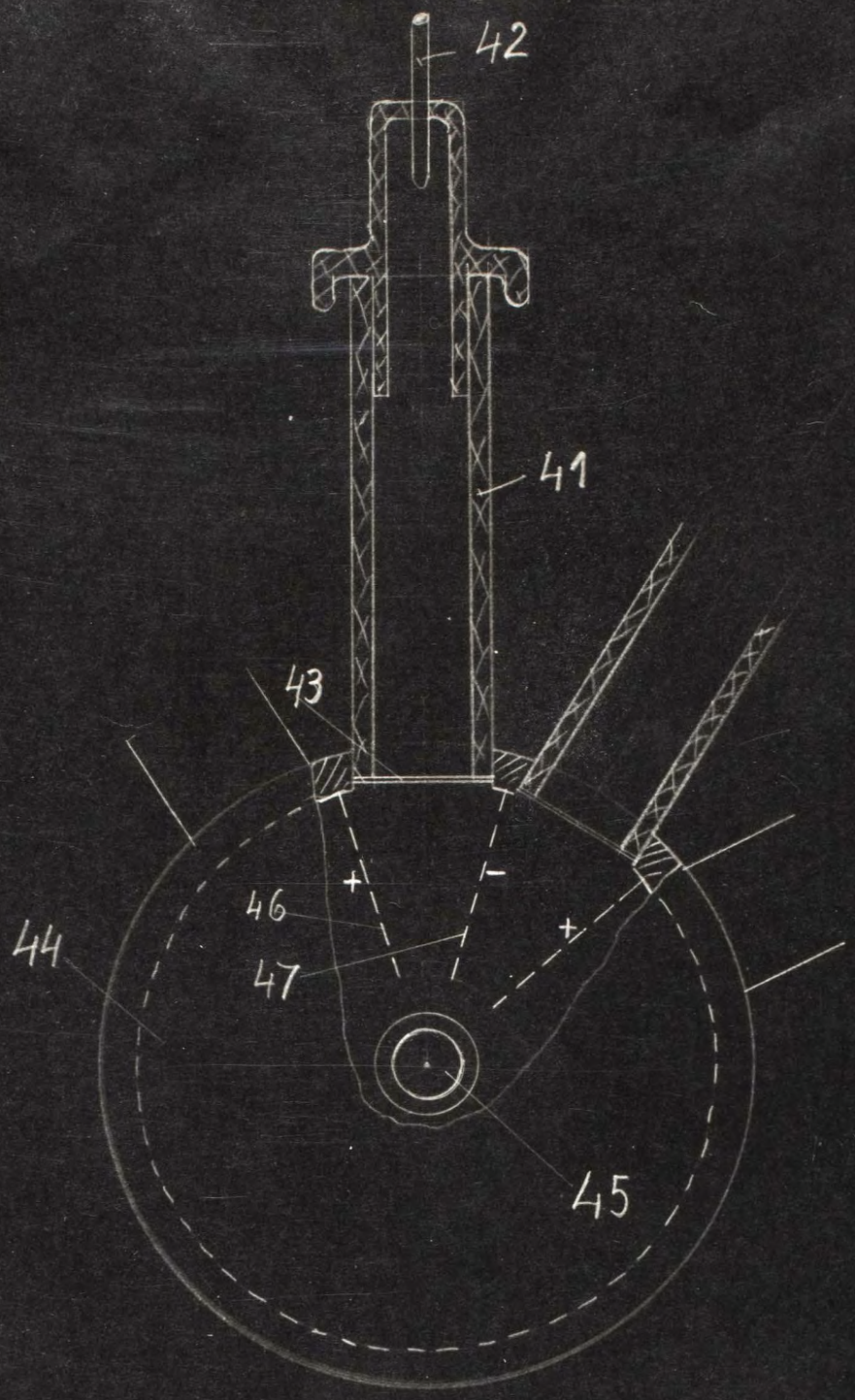


Fig 4.

12 March

4.

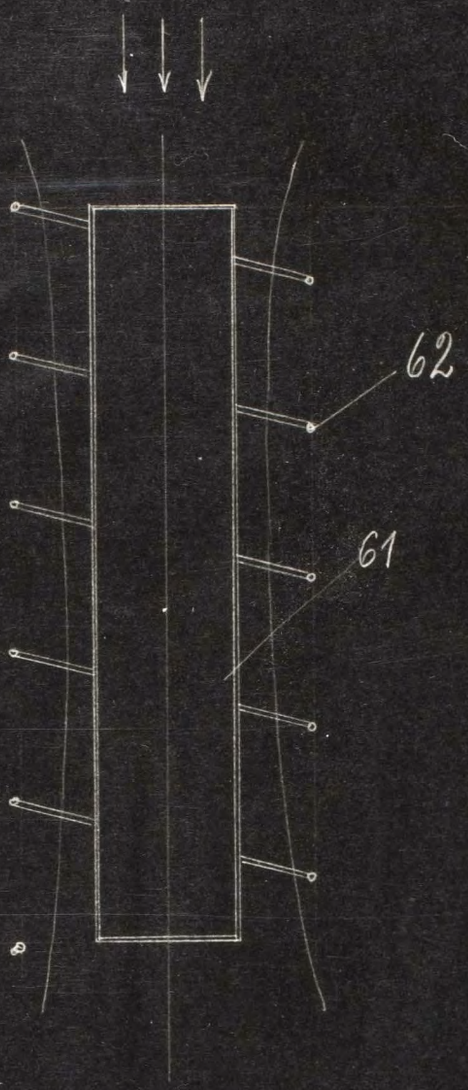


Fig. 6

12 March

6

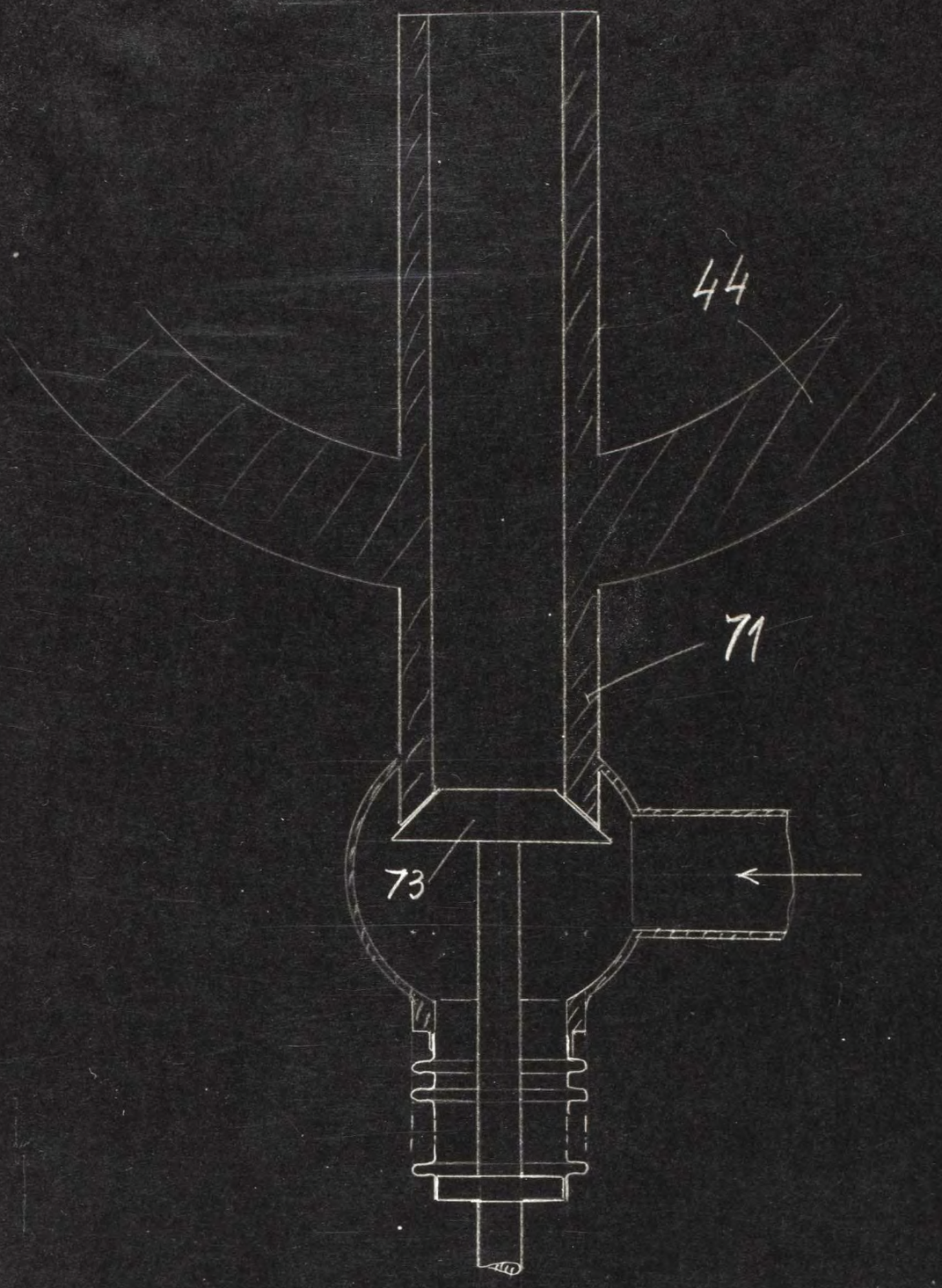


Fig 7

12 March

7

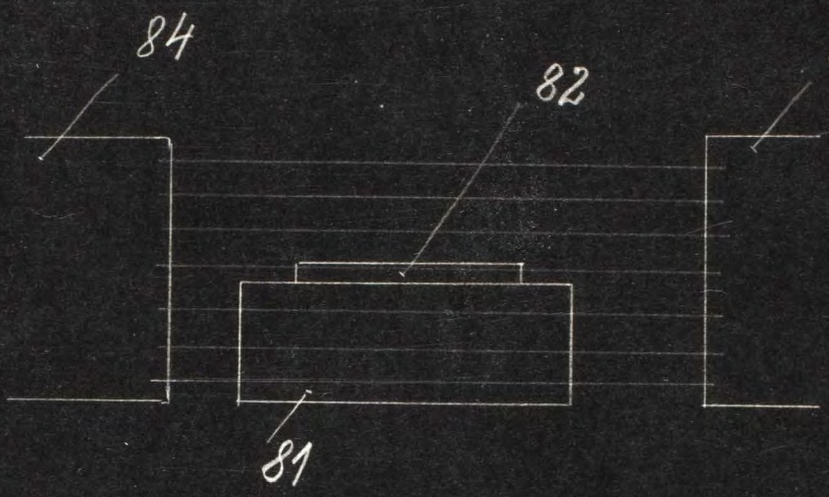


Fig 8.

12 March

8.

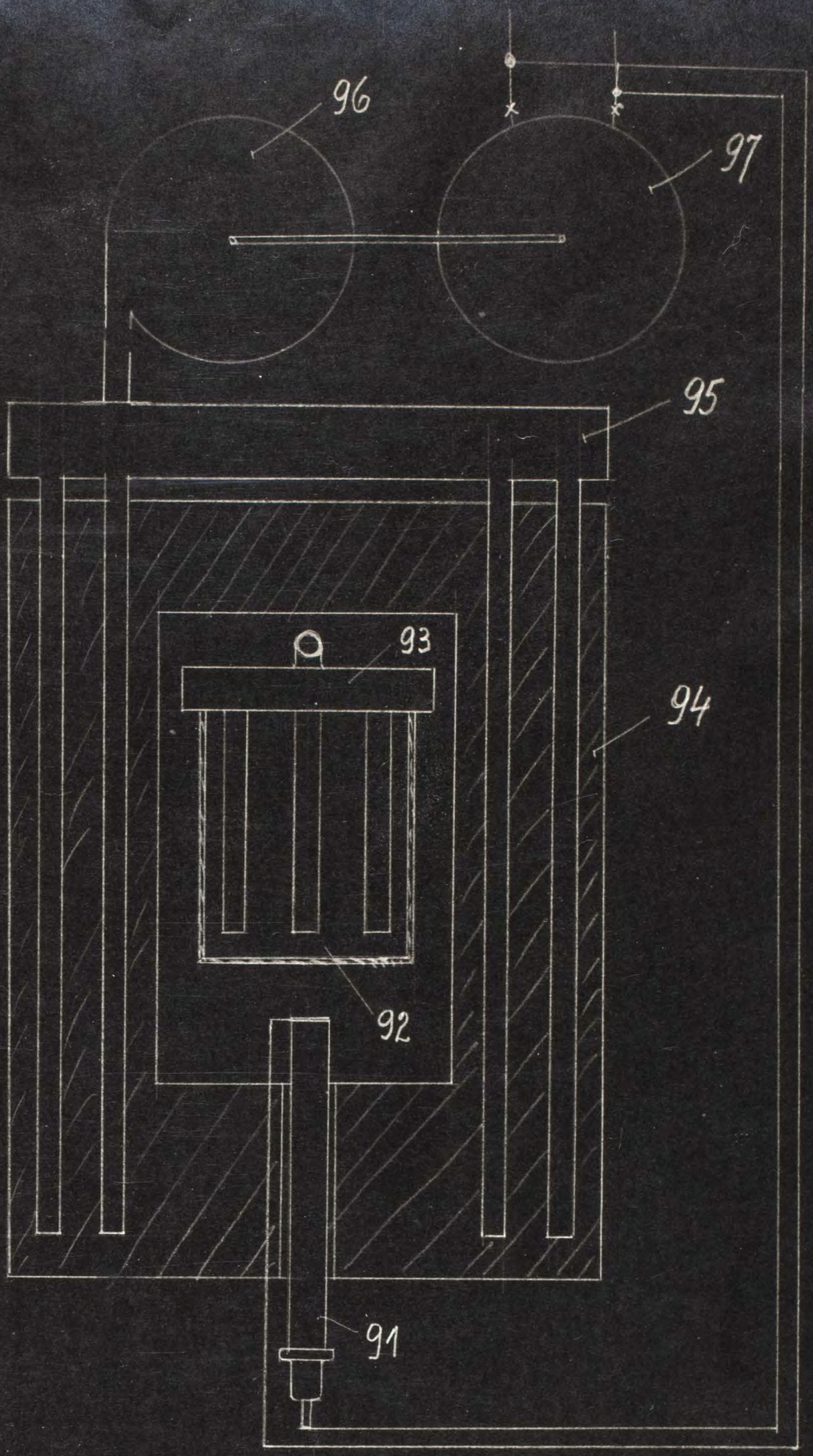


Fig 9

12. March

9.

20 meter

2 cm

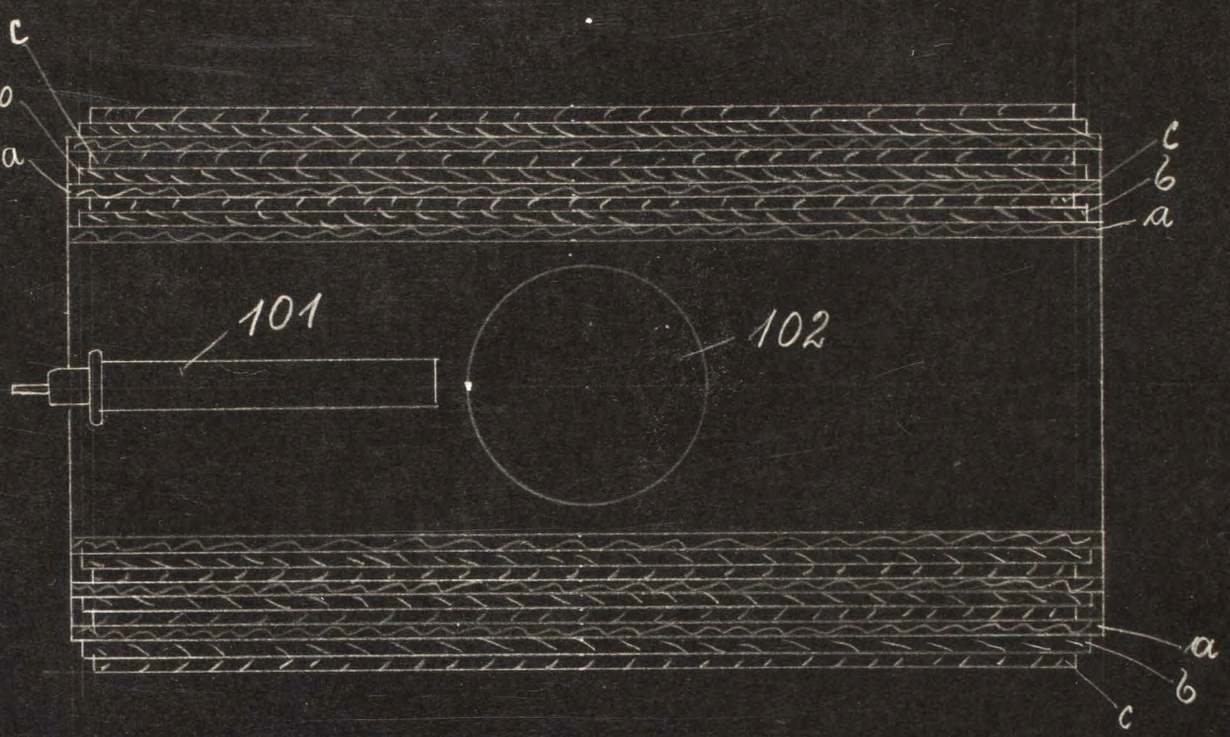


Fig. 10.

12 March

10

2 Copy

Patents Form—No. 1. No Charge for the Form.

PATENT

£1.

PATENTS & DESIGNS ACTS, 1907 to 1932.

(To be accompanied by two copies of Patents Form No. 2 or of Patents Form No. 3.)

Provisional Specification

APPLICATION FOR PATENT.

(a) Here insert (*in full*) name, address, and nationality of applicant or applicants (including the actual inventor).

(a) I (or We) ~~Transmutation of chemical elements~~ Leo Szilard a citizen of Germany and subject of Hungary Strand Palace Hotel, Strand, London

..... do hereby

declare that I am (or we are) in possession of an invention the title of

(b) Here insert title of invention.

~~which is~~ (b) Transmutation of chemical elements

(c) State here who is or are the inventor or inventors.

that (c) .....

claim.....to be the true and first inventor.....thereof, and that the same is not in use by any other person or persons to the best of my (or our) knowledge and belief; and I (or we) humbly pray that a Patent may be granted to me (or us) for the said invention.

Dated the 16th day of March, 1934

(d) To be signed by applicant or applicants and, in the case of a Firm, by each partner.

(d) .....

.....

.....

.....

Filed 12.3.34

NOTE.—One of the two forms on the back hereof, or a separate authorisation of agent, should be signed by the applicant or applicants.

To the Comptroller,
The Patent Office, 25, Southampton Buildings,
Chancery Lane, London, W.C.2.

(Y8388) Wt 15370/3531 30,000(2) 11/32 H & Sp Gp 102

(1) *Where application is made through a Solicitor, Patent Agent, or other authorised representative.*

I (or We) hereby appoint.....

of .....

to act for me (or us) in respect of the within application for a Patent, and request that all notices, requisitions, and communications relating thereto may be sent to him (or them) at the above address.

Dated the.....day of....., 193....

* To be signed by applicant or applicants.

* .....

.....

.....

.....

---

(2) *Where application is made without an Agent* (*Rule* 7).

I (or We) hereby request that all notices, requisitions, and communications in respect of the within application may be sent to

.....

..... at* .....

* The address must be in the United Kingdom.

.....

Dated the.....day of....., 193....

† To be signed by applicant or applicants.

† .....

.....

.....

.....

Transmutation of Chemical Elements.

It has been demonstrated that if atoms or nuclei, e.g. hydrogen atoms (or protons), heavy hydrogen atoms, referred to from now onwards as diplogen, (or diplogen ions, referred to from now onwards as diplons) etc. are shot at chemical elements, a definite fraction of those shooting particles will cause transmutation in many elements. (How large this fraction is will depend on the nature of the element, the nature of the shooting particle, and its velocity.) If one uses the above mentioned particles and shoots them on light or heavy hydrogen lithium (6) or lithium (7) or other elements a certain proportion of the particles lose their energy through ionising the substance through which they are shot, and only a fraction of the shooting particles will meet a nucleus of the substance before losing so much energy that the shooting particle is unable to cause transmutation in nuclei which it meets. Of these particles which meet a nucleus in their path (while still being in possession of a sufficiently large fraction of their initial energy) again only a further fraction will be able to penetrate the nucleus, (will be able to cause a transmutation); if the shooting particles are positively charged they are repulsed by the positively charged nucleus, and the probability of their penetrating the nucleus is a function of their relative velocity.

This probability rises rapidly with increasing velocity of the shooting particle and eventually reaches unity at a velocity which depends both on the nature of the shooting particle and the nature of the bombarded element.

However, even if this probability is equal to unity we still have to face the fact that a shooting particle has to travel for instance in air a large distance ~~of about 1000 m~~ in order to encounter a nuclear collision (which may cause transmutation), but due to the energy loss which it suffers through ionising the air its range ~~is only of the order of a meter~~ comparatively small if its initial velocity corresponds to several million volts energy. Only a ~~small~~ fraction or of the above mentioned shooting particles can therefore produce transmutation if shot into air or other substances or similar characteristics concerning ionisation losses and nuclear collisions. Under such ~~circumstances the transmutation of elements by shooting the above mentioned particles through substances of such characteristics is no practical proposition.~~

There are three main objects of the transmutation of elements which we shall discuss here:

1. The liberating of energy for power production.
2. The utilisation of particles which are emitted simultaneously with the transmutation or with a certain lack of time.
3. The production of elements which are capable of spontaneous transmutation (radio-active elements) and the storage of energy by means of such elements.

Radio active substances.

It is possible 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, most of the radio active elements produced by the bombardment of these light elements with protons or dpha 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 with good efficiency as the ionization loss gets too large. It is, however, possible to produce with good efficiency (both from lighter and heavier 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) atoms (or nuclei) and light elements including heavy hydrogen itself (diplogen) are produced.

In the accompanying drawings Figure 1 shows ~~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 for instance of gaseous diplogen or a diplogen compound or lithium, causing transmutation. The substance 13 is surrounded by a layer 14 of about 1 metre thickness and an average density above 1 gramm per cubic c/m.

If a substance which is mixed out of compounds of a large number of elements in such a way that it should contain in about equal molecular quantity (the number of gramms proportional to the atomic weight), all the elements (either free or in compounds) of the periodical system, with the exception of the rare gases, Rhenium, Masurium, and the radio active elements (but including uranium, thorium and all the alkali elements) is exposed to the penetrating radiation.

radiation of substance 13 (the acting agents of which radiation apparently are uncharged nuclei the mass of which are about equal to the mass of a proton or multiples of the mass of a proton), the substance X (after the exposure to the radiation) contains spontaneously transmuting elements, the time of disintegration of which is large as compared to the time of disintegration of most of the before mentioned radio active elements which can be produced by the direct bombardment of light elements with fast charged particles.

The efficiency can further be increased by measuring which of the elements in substance X do not contribute substantially to the radio active element which we want to produce and by eliminating those elements from the substance out of which we compose the layer 14. Such a measurement can be easily carried out by means of the methods that are well-known in every physical laboratory. After one has selected those elements or that element which is chiefly responsible for the production of the radio active substance we want to produce, one can, by separating the isotopes of these elements or that element and by measuring separately for every isotope this alone its contribution to the production, select the most suitable isotope. By building the layer 14 of this isotope a further increase of efficiency can be attained.

These are the essential features of the 15 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 the mean free path of the neutrons for this process or larger of 1 metre. 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 production of such radio active substances with good efficiency leads to a system of energy storage and such substances can be used as accummulators for driving cars, vessels, aeroplanes and so on. They are indeed accummulators of a very small weight.

There are two ways in which these "accummulators" can be utilizedfor power production (for driving an engine). Fig. 3 shows an example of one of these two ways. 21 is a boiler for the production of water or mercury vapour. The heat in the fluid is generated by the absorbtion of the penetrating radiation of the radio active substance in the fluid direct. The radio active substance is dissolved in a metal out of which the tubes 22, 23 and so on have been drawn. The heat which is generated

in the metal sheets by the absorbtion of the charged particles emitted by the radio active substance is in this way also efficiently transmitted by convection to the liquid in the the tubes 22, 23 etc.

If one uses a radio active substance which practically does not emit any charged particles but only uncharged nuclei of the mass of a proton (or a multiple thereof) one has the great advantage of being able to generate the heat in the water or mercury without having a substantial heat transfer from a solid surface to the liquid.

Fig. 3 shows an example of a direct production of electrical power by the "accumulator". 31 is a radio active substance emitting charged particles, for instance positive electrons. 32 is a vacuum tube the entrance of which is hermetically sealed by a thin sheet of metal 33 (a Lenard window). The positive electrons are shot through the Lenard window and the vacuum so that an electric current enters the electrode 34. The electrode 34 is connected to the positive pole of a high tension system which is fed by the said current. A grid 35 which is negatively charged in respect of the electrode 33 (the Lenard window) prevents secondary (negative electrons) electrons emitted from the Lenard window from reaching the electrode 34. The tube 32 is immersed in oil and an electric coil 36 produces a magnetic field parallel to the axis of the tube which leads the positive electrons in spirals to the electrode 34.

The essential features of the system of accummulation as described are the following:

The production of radio active substances by using electrical energy to cause transmutation, the generation

of electrical energy by means of the radio active substance produced by letting the charged particles which it emits pass through a vacuum space or alternatively by using its radiation to heat up a gas or a fluid, the heat of which can be utilized in a thermic engine, for instance a steam turbine; means to utilize the power generated by the radio active substance for driving a car, a vessel or an aeroplane.

Methods and Apparatus for causing Transmutation.

The methods described hitherto were characterised 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. A further limitation of that method lies in the difficulty of producing as large ion currents as would be needed for industrial purposes. The following method is free from these limitations:

If we were to maintain a very large concentration of energy in a space filled with atoms of such elements which will suffer transmutation, if the atoms (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, ~~xxx it xxxxx xx xxxxxxxx xx xx xxxxxxxxx xxx xxx xxxxxxx xxxxxx~~ One 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 hydride (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 to store electrical energy and discharge this condensor 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 e.g. into the "transmutation space" filled 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 a sufficient supply of energy sufficiently to heat up 1 cubic cm. of diplogen (an amount of diplogen that would fill 1 cubic cm. under ordinary pressure and temperature) ~~to 500, million centigrades.~~ The energy required is ~~of~~ the order of magnitude of the heat that would be needed to heat up 1 kg. of water by 50 to 100 centigrades.

Fig. 4 shows an illustration of the method. 41 is a discharge tube. 42 an electrode in this discharge tube. 43 a thin metal window hermetically sealing the vacuum in the discharge tube and allowing the passage of charged particles from the discharge tube into the interior of the vessel 44. A number of other discharge tubes similar to tube 41 can be placed around the vessel 44 in a position similar to that of 41, and all these tubes can be operated simultaneously. Each tube may have a separate set of electrical condensor and all these condensors may be discharged across the corresponding discharge tube simultaneously byusing an electric impulse to bridge all the spark gaps simultaneously. Fig. 5 shows how the tube 41 is connected through a spark gap 51 to a condensor 52 which is fed by direct current through the chokes 53 and 54.

The corpuscular rays of all the discharge tubes are focused on a small area 45 the "transmutation area" which is only a small fraction, e.g. of the order of less the volume of

one millionth to one thousandth of a millionth of the volume of the vessel 44. The ration of the two volumes to be chosen will depend on the density of matter in the transmutation area; one can e.g. replace 1 cubic cm. of diplogen gas (having a density corresponding to ordinary pressure and temperature) by a solid compound of diplogen which will hold the same amount of diplogen in a few cubic millimetres. In the interior of the vessel 44 a low pressure is maintained but sufficient gas is left (if cathode rays are used) to compensate the negative space charge during the discharge; to the same effect electric fields can be maintained between conductors 46 and 47 which will remove part of the secondary electrons produced by the cathode rays during the discharge.

The duration of the discharge can be chosen so as to suit the purpose and may be anything between 10^{-5} sec. and 10^{-7} sec. If we had for instance 1 cubic cm. of diplogen gas enclosed in a small container having very thin walls in the transmutation area 45 and if we had a pressure of one atmos. before the discharge we shall have an enormous pressure after the discharge which would burst not only the thin walls of the container but would burst much thicker walls. However, the displacements during the explosion are proportionate to the square of the time that has passed since the starting of the explosion, and it is therefore possible to maintain for a short period of time a sufficiently high density of the matter (e.g. of the diplogen gas) in the transmutation area if the "heating up" of this area is brought about by the corpuscular rays in a

sufficiently short time. It is important to maintain a sufficiently high density in order to have a sufficient number of collisions (to have a sufficient chance for a collision causing transmutation) between the nuclei in the transmutation area while the energy concentration is high. From this point of view it is an advantage to start with a very high density such as one gets if one uses liquid or solid compounds of diplogen (or liquid or solid forms of the other light elements that one may use). If the "heating up" occurs in a short time the heat losses through radiation and conduction are tolerable. As the vessel 44 has a very large volume the rise of pressure in it after the explosion, is tolerable.

Fig. 6 shows a different form of the transmutation area. 61 is a thin walled tube which is hermetically sealed and which contains the gas which is to be heated up. A strong magnetic field is maintained parallel to the axis of the tube as indicated by the magnetic lines of force drawn in Fig. 6. This magnetic field is generated by a coil 62 which is also indicated in the Figure, and has the purpose to coil up the ions and electrons into which the gas dissociates when heated up. Therefore the expansion of the gas perpendicular to the axis of the tube will slow down under the influence of the magnetic field. F The arrows indicate the corpuscular beam which effects the heating up.

Fig. 7 shows a further form of the transmutation area. 71 is a thick walled tube of lead or another heavy metal which opens freely into the vessel 44. By means of a valve 73 gas is let immediately preceeding the heating up into the tube 71. After the heating up the wall of the tube 71 is destroyed but due to the large atomic weight of the metal used the escape of the gas

in directions perpendicular to the axis is slowed down.

Fig. 8 shows still another form of the disintegration area. On a block of a heavy metal 81 we have a thin sheet 82 of a compound of diplogen for instance LiD in solid form and magnetic lines of force parallel to the surface generated by the magnet poles 84 and 86. The heating up may be effectuated by cathode rays or heavy ions (e.g. mercury), the heavy ions having the advantage of ionising more intensely but the disadvantage of creating a positive space charge along their path.

An essential features of this method is the heating up of a definite area by means of fast particles which have been accelerated electrically (while being electrically charged) in vacuum. The fast particles represent energies corresponding to 100,000 to ten million volts, and can heat up the transmutation area to anything between 100,000 to one billion degrees contigrade. An essential feature of a suitable method is to produce the heat in a very short time by applying to a discharge tube, adapted to eject the said fast particles, a high voltage for a very short time. This can be effected by storing the energy for the discharge mechanically, magnetically or by means of an electric condenser.

If an electric condenser is used it is possible to apply a very high voltage and thereby to store a very large energy by loading the condenser in a very short time, e.g. 10^{-4} to 10^{-5} sec. and discharging the condenser through the discharge tube in a time shorter than 10^{-5} sec. For a time of 10^{-4} to 10^{-5} sec. a condenser x built for the purpose is able to stand a much higher voltage than it would be able to stand for a longer time.

It has been thought that artificial transmutation cannot be used for supplying power for engines because of the fact that if you shoot protons or diplogen into any chemical element the energy liberated in the transmutation process will be less than the energy of the fast protons or diplogen. This conclusion is fallacious.

It is true that if you shoot the said particles at any element with a translation energy which is as large as the energy liberated in a transmutation when the particle strikes a nucleus of that element, a large fraction of the particles will not cause transmutation and the power output will therefore necessarily be smaller than the power input. However, if one accelerates the said particles with a voltage which is sufficiently high so that the energy of a single proton or diplogen is larger than the energy liberated in a single process of transmutation one can produce radio active elements which will transmute subsequently with sufficiently good efficiency to be able to use the energy which they liberate for driving engines as pointed out above. But that conclusion is fallacious for another reason.

Fig. 9 shows an example where atomic transmutation is used for power production. 91 is an electrical discharge tube which ejects fast protons or diplogen into the transmutation chamber 92 which is filled with diplogen (or lithium compound). 93 is a boiler to which the heat produced by the particles shot into the chamber 92 by the tube 91, and the heat produced by the radiation emitted in the transmutation process

and absorbed in the chamber 92 is transmitted. The neutrons emitted in the transmutation process (particle of the mass of a proton or multiples thereof having no charge) are part of the penetrating radiation emitted from the chamber 92. 94 is a thick wall containing elements, the nuclei of which react with these neutrons in which process energy is liberated. 95 is a second boiler to which the heat liberated in 94 is transmitted. The steam produced in the boiler is utilized in a steam turbine 96, which drives an electric generator 97. Part of the generated electric power is used to feed the tube 91 and part of it is available for other purposes.

One further reason for which the said conclusion is fallacious is the possibility of chain reactions. We can bring about very efficiently transmutations by exposing two different elements a and b to the transmutation radiation of each other if those elements are so chosen that the following conditions should be fulfilled: a should emit in transmuting one or more different kinds of neutrons α_1, α_2 Of these neutrons one or more e.g. α_1 should cause a transmutation of „b" in which one or more neutrons $\beta_1, \beta_2 \ldots$ are emitted. Again one or more of these e.g. β_1 should cause „a" to transmute and to emit one of the above mentioned neutrons e.g. β_1. It is essential that α_1 should be different from β_1. All these neutrons have a mass of the mass of a proton or a multiple thereof, and penetrate layers of the density 1 in depths of the order of magnitude of metres. It is therefore necessary to have the two substances packed in large masses together either mixed or in layers alternately following each other.

~~Fig. 10 shows~~ An example of a plant for carrying out transmutation as described. 101 is the discharge tube emitting fast diplogen ions into the transmutation chamber 102. 102 is surrounded by a thick wall built of alternate layers of "a", "b" and "c". The purpose of "c" is to have a third element, the nuclei of which react with neutrons that form a link in the chain reaction between "a" and "b". Such a third element is in certain cases needed to prevent an explosion.

With reference to Fig. 2 it must be added that a number of boilers may be placed close to each other in such a way that the neutrons emitted from the walls of the tubes should be find geometric/conditions favourable for their absorbtion in the fluid within the tubes. In order to absorb the gamma radiation one can cover the tubes with lead; this is not necessary in case of a mercury vapour plant in which case the fluid within the tube will absorb the gamma radiation direct.

An important use of the neutrons emitted in transmutation processes is the radiation of living cells for the purpose of getting variations (mutations) of the offsprings. The fact that the neutrons act essentially by colliding with individual atoms in the cell and affect thereby in each case a very small area of the cell explains why one gets better results with neutrons than with X-rays or charged particles. The latter ionise a large area and affect many gens (chromosomes) at once so that one gets simultaneously too many changes; it is therefore difficult to get hereditary changes along definite lines. With neutrons one can produce a change, then radiate the offspring with neutrons once more, and pick out ~~xxxx individuals, xxx~~ the offspring of ~~xxxx individuals xxxx xxxx~~ one of the individuals which show another change along the line desired.

Fig. 11 shows the principle of an arrangement suitable to be used in a heating up device similar to that shown in Fig. 4. In the transmutation area 45 in Fig. 11 we have diplogen or hydrogen and lithium (7). By heating up suddenly this area by means of a sudden discharge of the vacuum tube 41 etc. we produce transmutation in 45. In the case of the combination hydrogen and lithium for instance we get alpha particles. Size of 45 and the density of the active agents in it (the amount of hydrogen and lithium) can be so chosen that the alpha particles generated in the transmutation process should lose sufficient energy through ionization to contribute a substantial part to the heating up of 45. The charged particles generated in 45 penetrate a second transmutation chamber 111 in which they produce a very sudden heating up through the ionisation losses in 111. We can therefore have a heavy element in combination with other elements for instance with diplogen or hydrogen in 111 and get a transmutation of the heavy element through the large energy which is suddenly transmitted by the charged particles coming from 45 generated in the transmutation process. We can select the combination of elements in 111 so that as a result of the transmutation a radio active element should be generated in 111 (through the collision of the nuclei of the elements placed in 111 with each other). We can also select the combination of elements in 111 so that neutrons should be emitted from 111 and have a thick wall 112 surrounding both chambers, the nuclei of which will react with the neutrons thereby either liberating energy or storing energy by transmuting into a radio active substance.

The following are the essential features of the invention:

1. The heating up of an area by means of rays produced by the acceleration of charged particles in vacuum.

2. High voltage and large currents to be applied for the production of the said rays in order to heat up the said area in an extremely short time.

3. Diplogen or the combinations of diplogen and lithium, or hydrogen and lithium, or hydrogen and other light elements, or diplogen and other light elements in the said area, or other combinations of two light elements.

4. The selection of the size of the radiated area and the density of matter in it, so that the charged particles produced in the transmutation process should get absorbed within the area to that extent that their contribution to the heating up of the area should be substantial.

5. The said area being surrounded by a second transmutation chamber which contains heavier elements or a combination of a light element, for instance diplogen or hydrogen with at least one heavy element; this second chamber being heated up very suddenly by the charged particles emitted by the first area when heated up.

6. A thick sheet of substance, for instance an combination of heavy elements exposed to the penetrating radiation (neutrons) of the first or second transmutation area having such elements in the sheet as will transmute into radio-active elements.

7. The use of radio active elements (produced for instance in the second transmutation chamber or according to point 6) for transmitting heat to a boiler (or to another thermic

engine) and their use in combination with a vacuum tube for the direct production of electrical power.

8. The use of the penetrating radiation emitted for instance by the first or second transmutation area (neutrons) for radiating living organisms for the purpose of producing mutations especially the production of producing mutations along a line by radiating subsequent generations.

9. In connection with point 2 the use of means for storing energy for the purpose of discharging a large amount of energy for all of a sudden in a discharge tube such means as electric condensors or combinations or an electric condensor and a coil storing magnetic energy.

→ 440,023

Patents Form No. 3.

Provisional Specifications

7840/34	Dated	12th March,	1934.
13947/34	..	9th May	..
17601/34	..	14th June	..
19157/34	..	28th June	..
19721/34	..	4th July	..
27050/34	..	20th Sept.	..
27507/34	..	25th Sept.	..

PATENTS AND DESIGNS ACTS, 1907 to 1932.

COMPLETE SPECIFICATION.

Transmutation of Chemical Elements.

I, Leo Szilard, a citizen of Germany of The Strand Palace Hotel, Strand, London, W.C.

do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:-

PATENTS FORM No. 3.

PATENTS AND DESIGNS
ACTS, 1907 to 1932.

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 utilization of the energy which has thus been stored for the production of heat and power, further to the liberation of nuclear energy and the utilization of the liberated energy.

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, boron 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 existence (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 with good efficiency as the ionisation loss gets too large. It is, however, possible to produce with good efficiency (both from lightand 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) atoms (or nuclei) and light elements, including heavy hydrogen (diplogen, also called deuterium) itself, are produced.

In the accompanying drawings Fig.1 shows an example

PATENTS FORM No. 3.

PATENTS AND DESIGNS
ACTS, 1907 to 1932.

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 gaseous 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 substance 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 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 radio activity 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

of a suitable arrangement. 11 is an electrical discharge tube ejecting a beam 12

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 ionisation 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 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 ionisation 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 ionisation losses are practically absent even in case of passage through heavy elements.) liberated in a nuclear reaction between light elements. The nuclear reactions between the light elements were brought about either by the bombardment of a target containing light elements with a beam of fast light atoms or by heating up a small space containing a light element. Now two further methods will be described for the liberation of the neutrons leading to the generation of radio active bodies. One of these is based on the fact that neutrons can be liberated from certain elements, for instance beryllium, by X-rays.

Fig. 5. shows an arrangement suitable for the production of hard X-rays, in which 1 is the primary

of a suitable arrangement. 11 is an electrical discharge tube ejecting a beam 12

of a transformer, the secondary 2 of 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 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 condensers 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 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, Bb or some other heavy element.

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 transmutation, if the atom (nuclei)

of a suitable arrangement. 11 is an electrical discharge tube ejecting a beam 12

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. One 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 condenser 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 condenser 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 Fig. 6, 27 is the window of the high voltage tube through which the fast electrons are ejected. The

of a suitable arrangement. 11 is an electrical discharge tube ejecting a beam 12

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 25cm. x 25cm. The voltage used to operate the electron tube may be three million volts. 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 50cm. x 50cm.

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 Fig. 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 radio active 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 radio active isotope from the irradiated element. Compounds in which the element in which we are interested are bound direct to carbon are very 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 reaction. in orderto 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 their 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.

Figs. 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, Fig 7. (shown in greater detail in Fig.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, Fig.8., pump a liquid for instance water or mercury through the pipe systems 107, 110, 111,Figs.7 and 8, thereby cooling the transmutation area 3, Fig.7.,and driving the heated liquid through the boiler 126, Fig.8. The boiler supplies steam to a power plant. The neutrons emerging from the sphere 3 act on a layer 9, Fig.7.

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 Fig.9. 401 is the cathode ray tube described in Fig.1. 402 is a sheet of 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(Fig.8.) Nevertheless the sheet can be sufficiently thick to utilize more than half the energy of the cathode rays. The X-rays emerging from sheet 402 penetrate the layer 3 and can liberate neutrons either from the layer 3 or from a substance 407 placed in the interior of the layer 3. For instance, if we have beryllium present in 407 or in 3, neutrons will be 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 reaction takes place the inner radius (r) of which is large compared with the mean free paths of the 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 a neutron are needed in the average in order to produce one new neutron.

$$A = w / af \; ; \; D = aw / 3 \; \therefore \; ; \sqrt{\frac{D}{A}} = \frac{a\sqrt{f}}{\sqrt{3}}$$

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 $l_o = \pi/2 \sqrt{D / A}$. 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 disintegration into its parts under the 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 spectograph. If, for instance, the value obtained by Bainbridge for beryllium by means of the mass spectograph which appears to be generally accepted at present is really valid, we have to conclude that beryllium is a metastable element and can disintegrate into parts with the liberation of energy, one of the parts set free in its disintegration being a neutron.

If we have an element which is metastable but the disintegration 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 X

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 all these 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 shows the reaction:

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

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

We shall call an element "F" which reacts with a 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.

(c) 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 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 the like. Other such elements, like for instance, - rhodium, transmute into a radio active element if they capture a neutron. If a radio active 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 radio active element.

By maintaining chain reaction in combination with means for leading away and utilizing the heat set free in the transmutation process energy can be produced and utilised 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 utilised for power production.

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

(1). A method of 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). A method and apparatus according to Claim 1. characterized by the said nuclear transmutation process leading to the liberation of neutrons being a nuclear reaction of diplogen (deuterium) with diplogen or other light elements, or other light elements with each other.

(3). A 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

a high-voltage canal ray tube, on a target containing light elements; for instance through the action of diplogen canal rays on a target containing diplogen.

(4). A 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). A 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 X-rays, generated for instance by means of a high voltage electron tube, on suitable elements, for instance Beryllium.

(6). A 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). A 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). A method 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). A 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). A 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) A 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). A 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). A method and apparatus for the production of radioactive elements or energy according to Claim 9, characterized by the said body containing Beryllium.

(14). A 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 sygan particles alternate, is maintained.

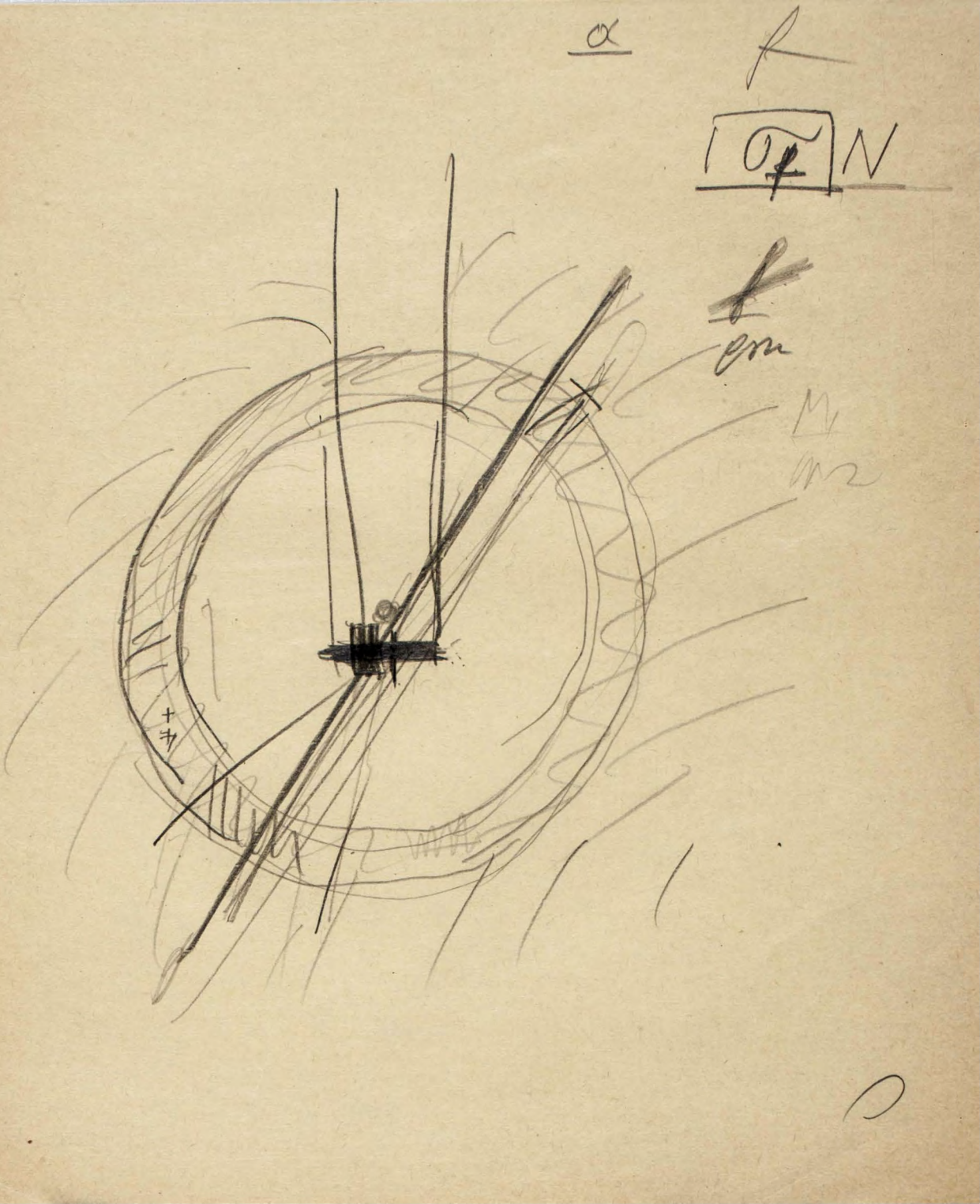
543

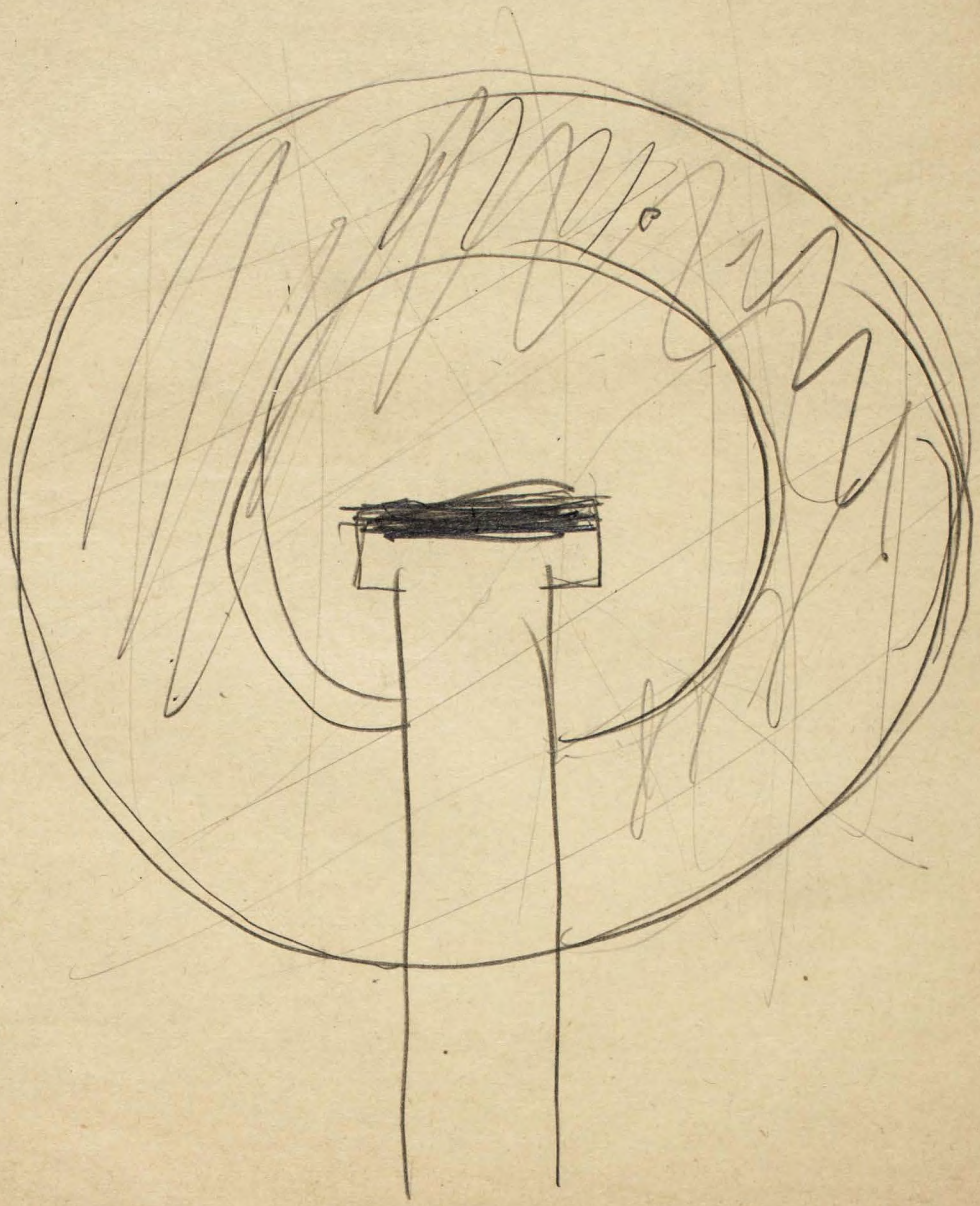
(15). A method and apparatus for the production of radioactive elements or energy according to Claim 9, characterized by the said body containing an element "K" which emits more than one sygma quanta for each captured neutron and one or more elements "L", "M" ..... which absorb strongly the sygma quanta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

(16). A 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 the day of 1935.





1) Pure Uranium

2) $NaIO_3$ Na_2UO_4

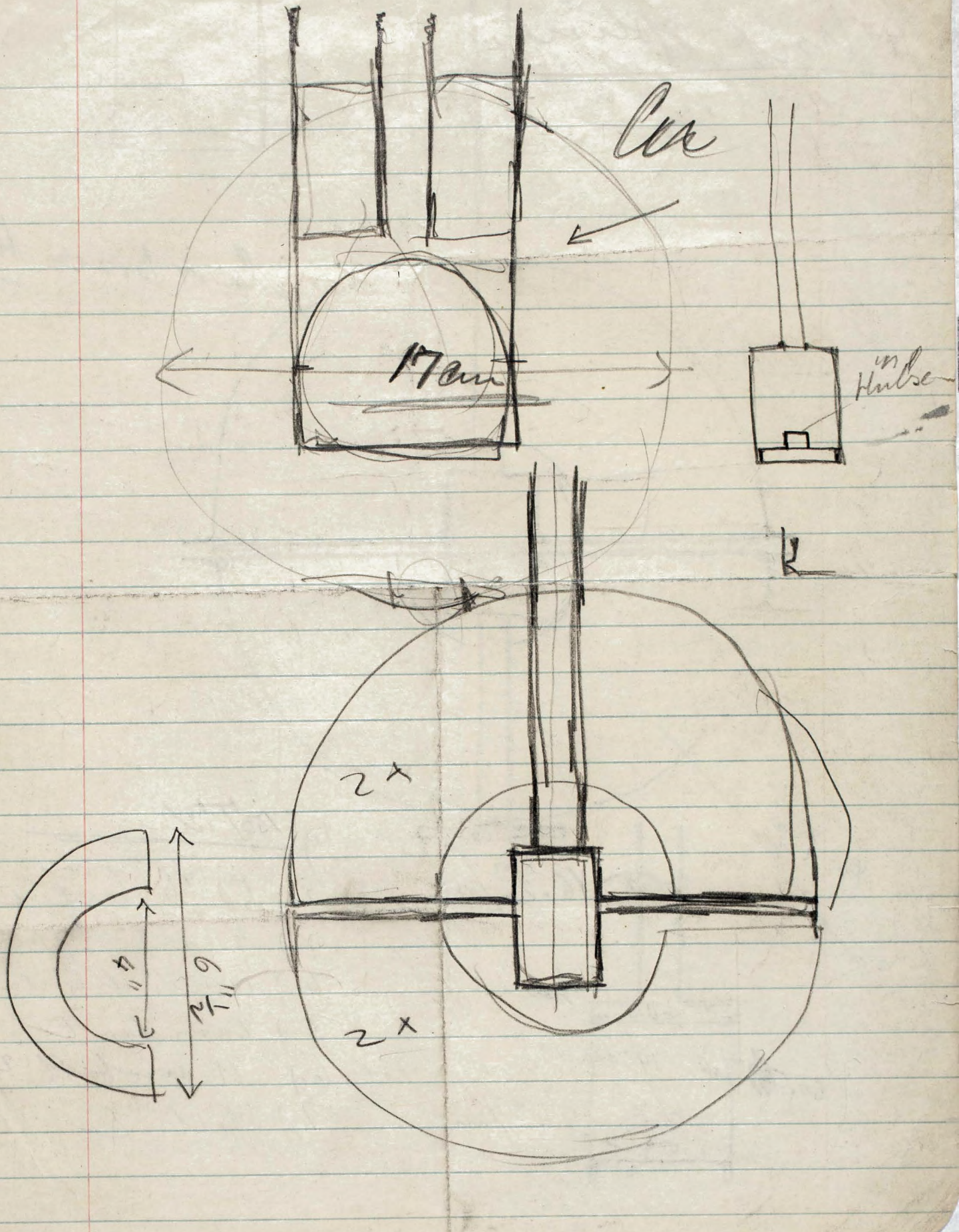
3) Na Uranate isotopic separation

4) Ordinary uranium separation

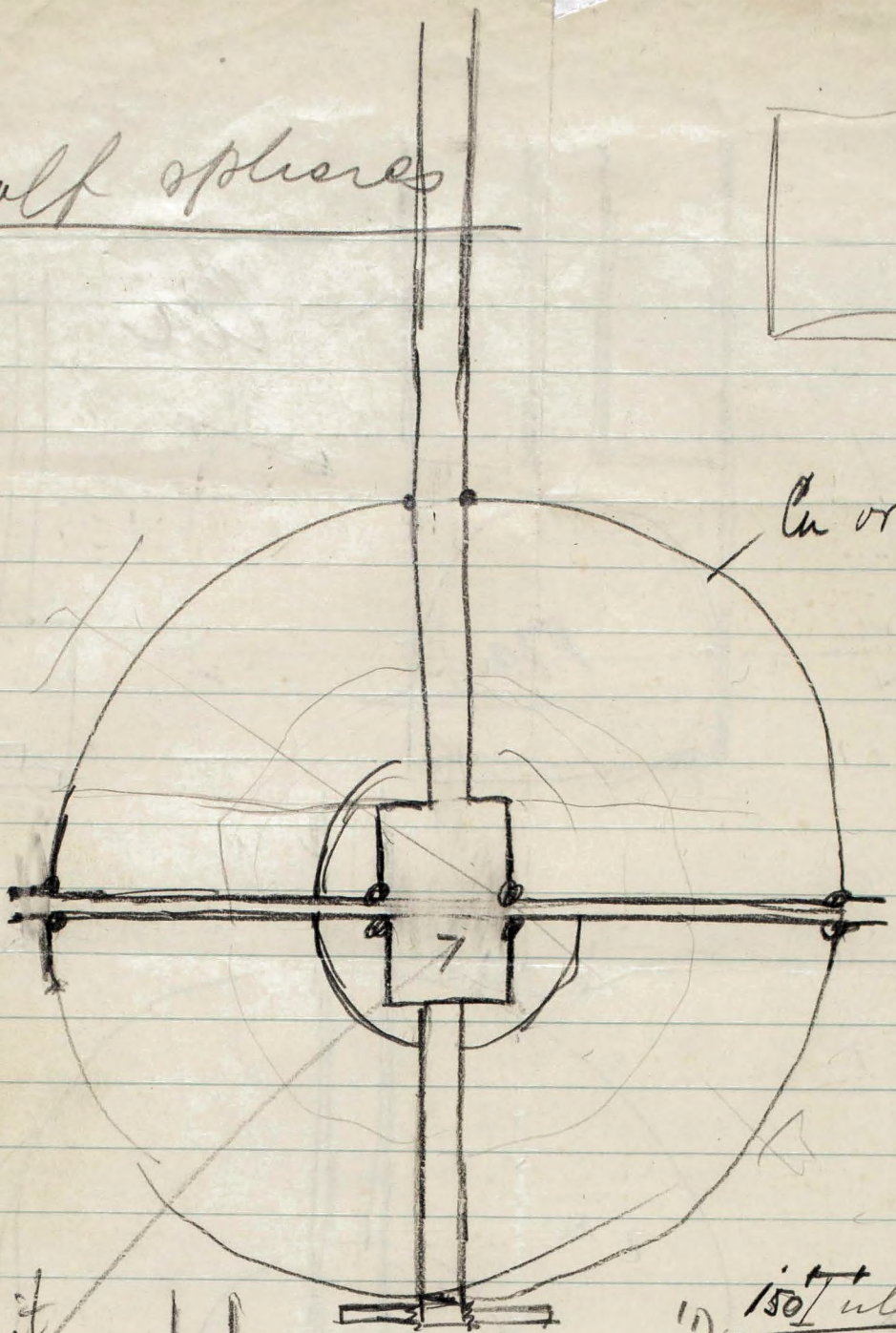
5) UF_6

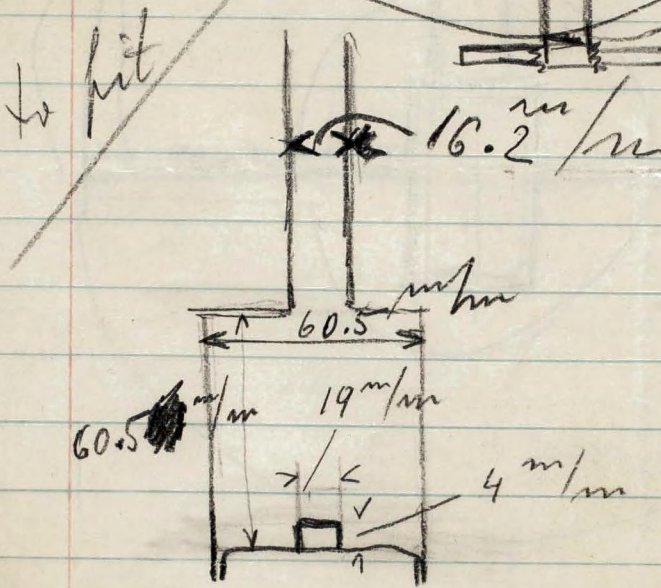
6) ~~~

150 x 25 = 00


17cm
Hülse
2x
2x

4 half splices





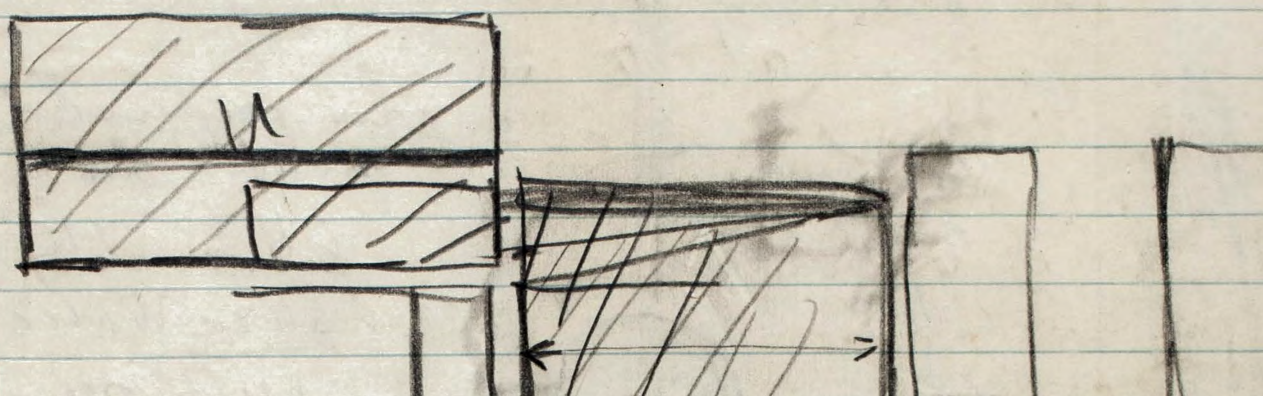
1) 150 T tubes
2.) 50 lb. lead
3.) 4 half stoppers
4.) Cond. chamber
5.) Camber
6.) 4 metal 2
7.) Sheet

V. Kürösy c/o Tamás c/o Schloss
690 Riverside Dr. Apt 2D
Audubon 37946

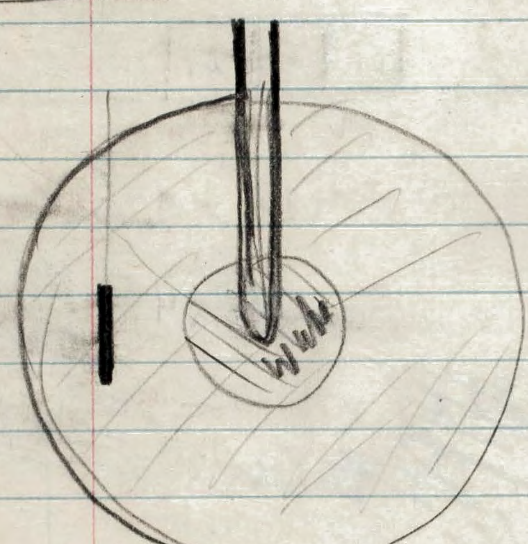
Zinn telephone: Mo-2-6906

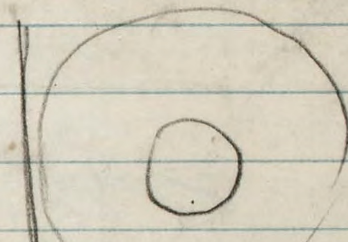
Zinn gets 300 – 1000 kicks/min
He recoil in 2 cm chamber at 5 Atm (?)

d = 33 cm, Source 2 Curie δ+D. —



Fermi





1 Mol | 9 cc Water
9 cc U_2O_5

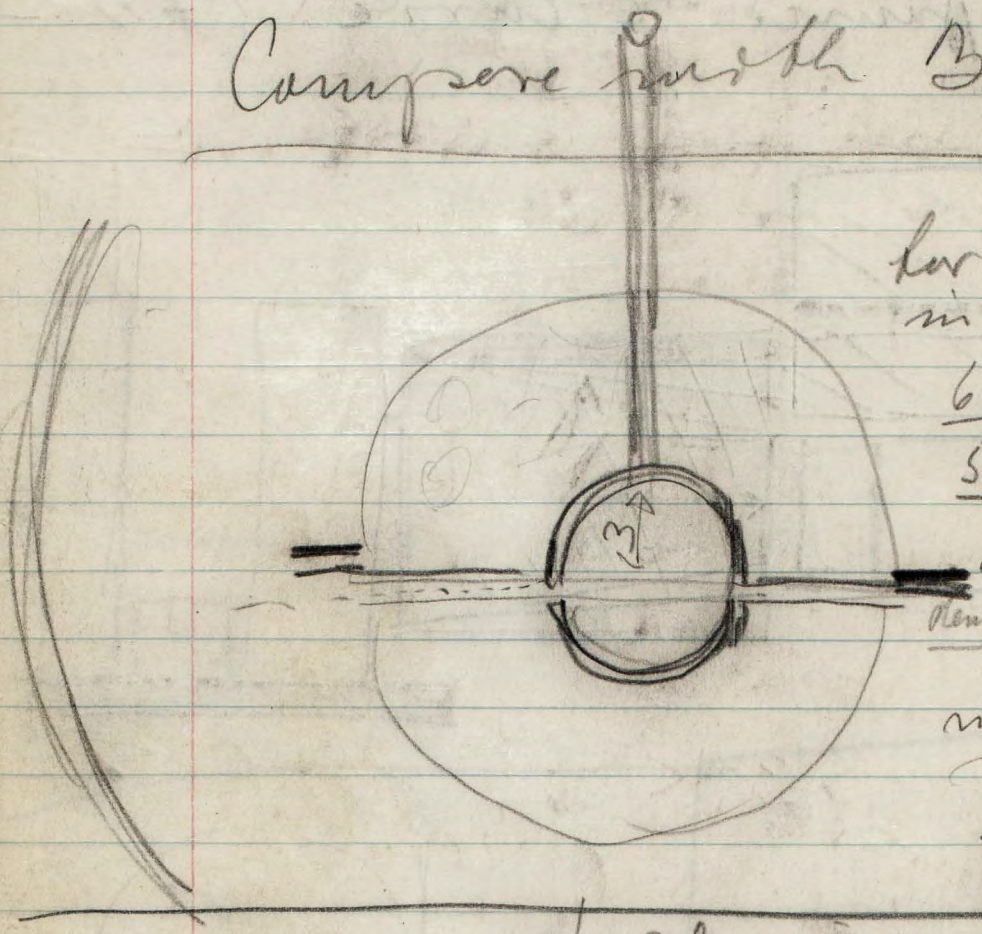
$9 \times 4 = \frac{36}{270} = \frac{12}{90} = \frac{1}{7.5}$ Mol

Fermi

density [redacted] 10 Metal powder

to 3× better.

Compare with Bi



for equal abs. in H2O as U

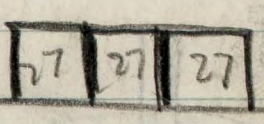
6H ~ 1U

54 cc Water

1U ≅ 27 cc [illegible]

dens 10.

mix in paraffin



Fermi type

$\frac{4\pi}{3} 20^3 = 420^3 = 4 \times 8 \times 1000$

~~36×4 =~~

$\frac{10}{3}$ 32 kg ~~[illegible]~~ ×1000 = ~~[illegible]~~

≅ 100 kg

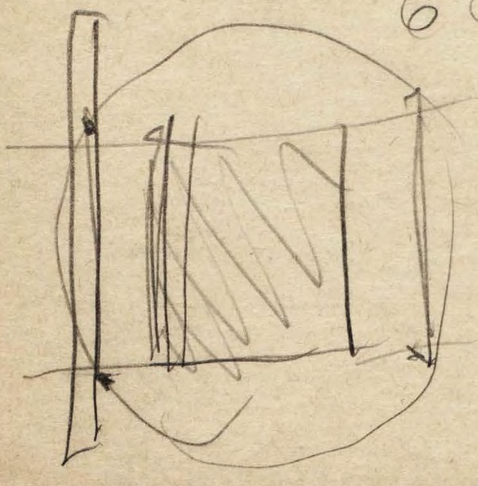
Mr. Gosman

Metropolitan can works

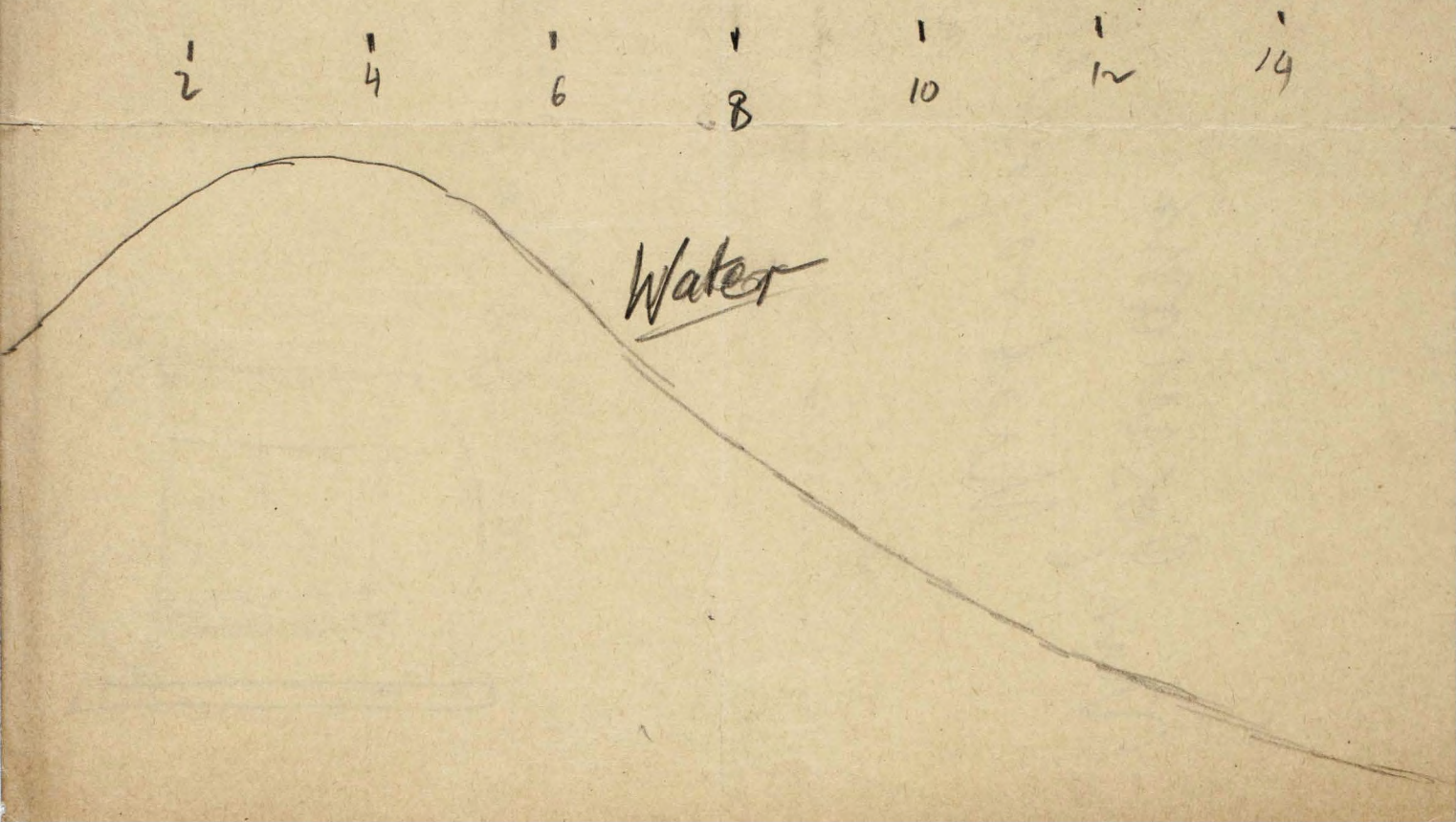
319 Greene street

WA5 ~~64~~ 72

60 to 90 page



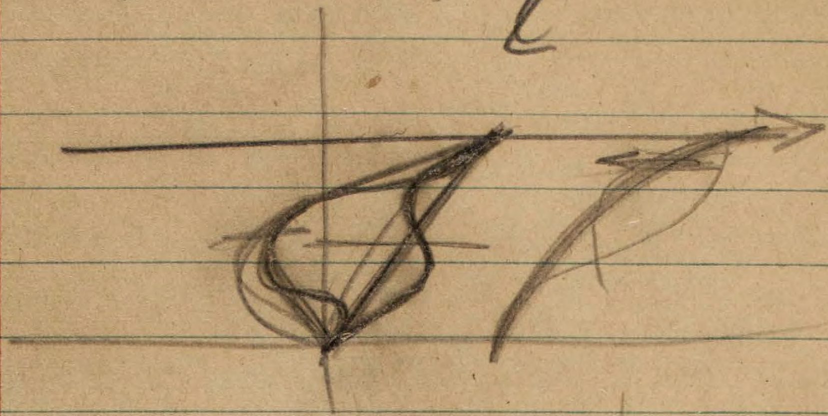
85 150


2
4
6
8
10
12
14
Water

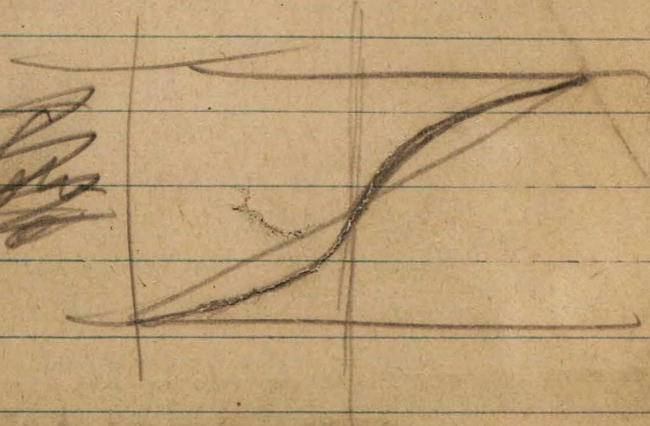
Pl. 3/48

235 E 44

$\frac{1}{v} \frac{\text{arbeit Hamilton } X}{d} = $



$\frac{1}{v}$ Arbeit



$i = v + \text{Const}$

$\frac{di}{dx} = \frac{dv}{dx}$ $\int i\,dx = 0$

$v''(x) = \text{Force} = L$

$v'''(x) = v'(x)$

$i = v + \text{Const}$

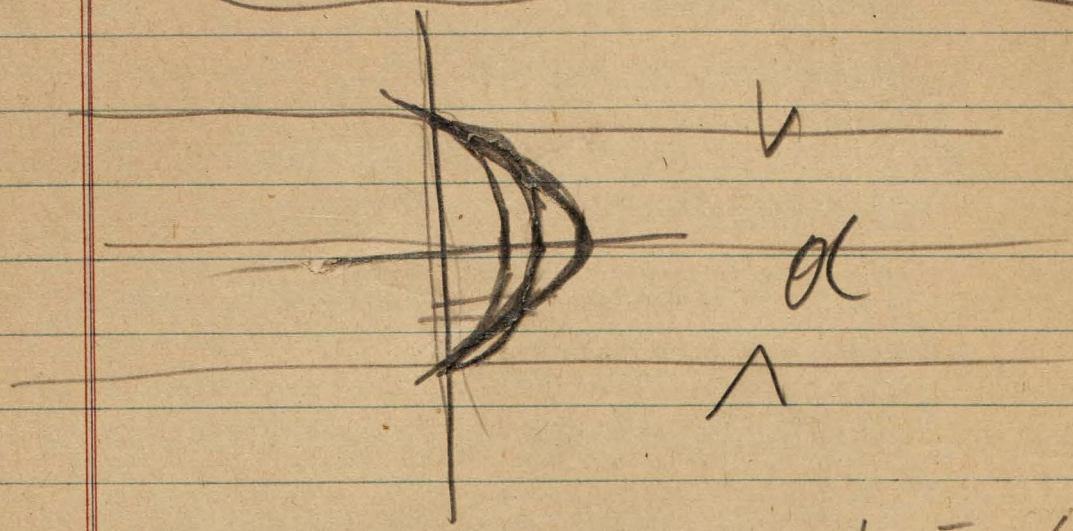
$\int_0^1 v''\,dx = 0$

$v_2' = v_1'$

2.37

$\int^1 v \frac{dv}{dx} =$

Druckabfall im Rohr



$l = 100\,10\,v$

p/cm

$\mu v'' = p$

1 m

500 kg/m

$10^{-5} \times 10^{1x} = 10^{-6}$ Watt
$= 10$ Joule
100 erg

$v'' = \frac{p}{\mu}$

$v' = \frac{p}{\mu} x + C$

$v = \frac{1}{2}\frac{p}{\mu} x^2 + Cx + C$

$v = \text{const} + \text{const} x - \frac{p}{\mu} x^2$

$v = 0$ for $x = \frac{dl}{2}$

$\text{const} = \frac{p\,dl^2}{4\mu}$

$$\frac{v}{\frac{q_1}{\varphi a} + \frac{q_2}{\varphi a} + \frac{q_3}{\varphi a}}$$

100 h 400 KWh

$$C_1 + \frac{p}{\mu} - \beta v = v''$$

to get C_1 $\int_0^l C_1 + \beta v \, dx = 0$

$$\beta \frac{v_m}{2} + \frac{p}{\mu} - \beta v = v''$$

100 KWE [illegible]

$$\alpha - \beta v = v''$$

1 KWh/l

600 Kcal/l

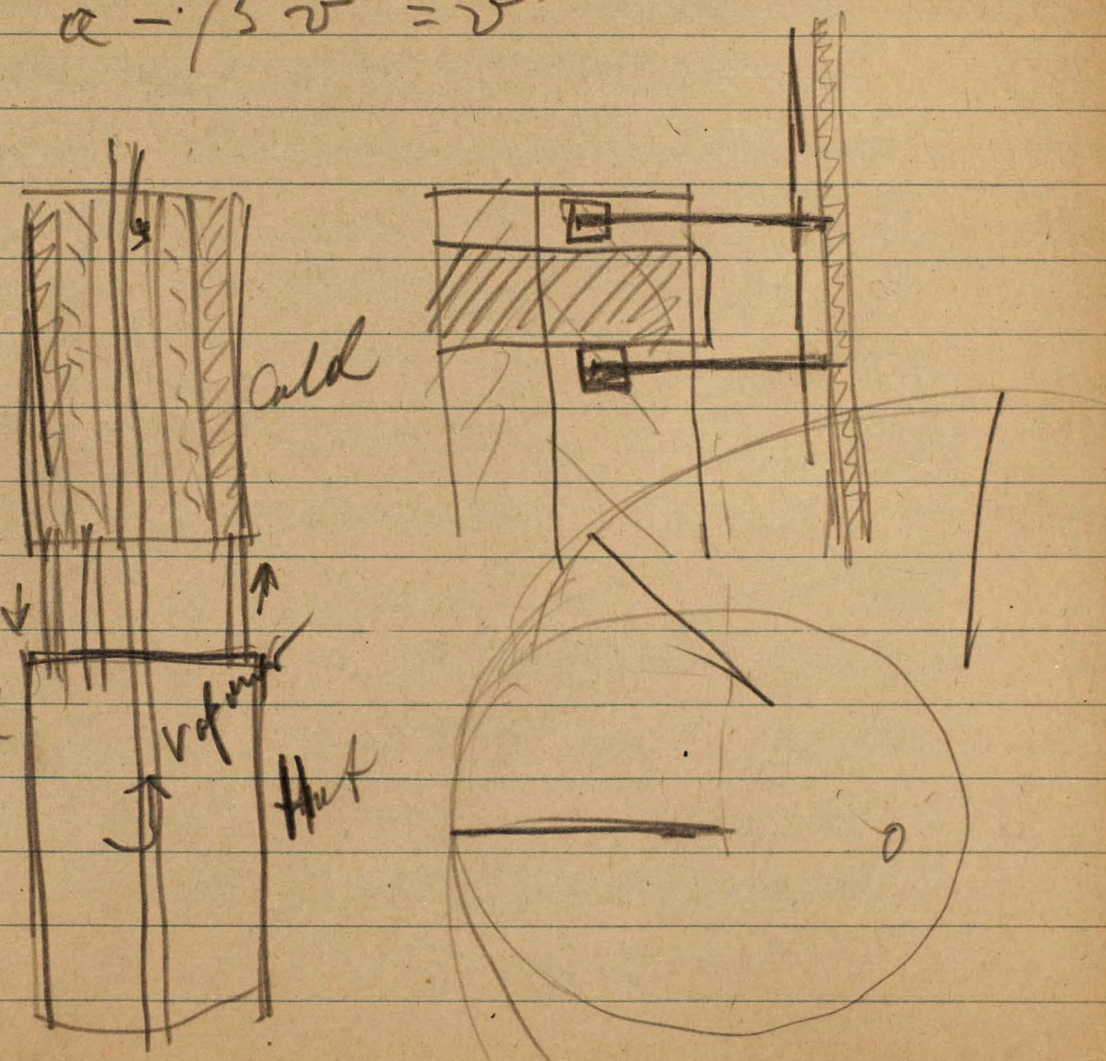
3×

200 Kcal/l

4 Watt sec/gal

4000 Watt sec

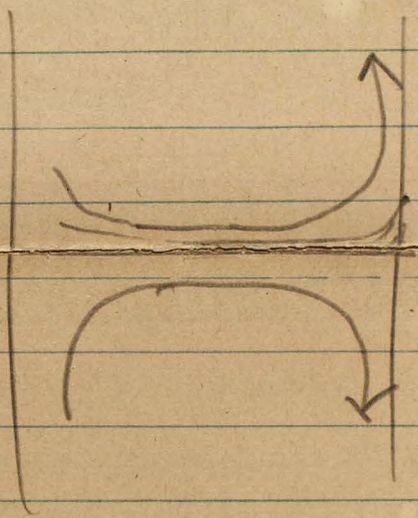
1 Watt h



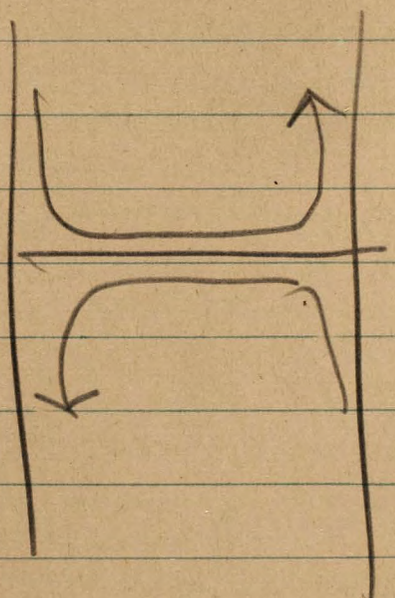
Löslichkeit $UO_2(NO_3)_2$
steigt
in Wasser
von 5,5°C 50,58 g/100g H_2O
52°C 67,76 g

2 Fälle

1)



2.)



$$\frac{1}{R_3} = \frac{1}{R_3^{\frac{1}{3}} \frac{3a}{1\alpha} + R_3^{\frac{1}{3}} \frac{3b}{3\alpha} + R_3^{\frac{1}{3}} \frac{3a}{3\alpha}} \cdot \frac{n\rho}{} +$$

$$+ \frac{1}{R_2^2} \frac{n\rho}{R_2^{\frac{1}{2}} \frac{3a}{2\alpha} + R_2^{\frac{1}{2}} \frac{3b}{2\alpha}} +$$

$1\ cm^2$

$$\frac{1}{R_2^2} \frac{n\rho}{R_2^{\frac{1}{2}} \frac{3b}{\alpha} + R_2^{\frac{1}{2}} \frac{3c}{\alpha}} +$$

$$\frac{1}{R_2^2} \frac{n\rho}{R_2^{\frac{1}{2}} \frac{3c}{\alpha} + R_2^{\frac{1}{2}} \frac{3a}{b\alpha}}$$

$H = \frac{i}{10}$

$3\ cm\ H = \frac{i}{30}$

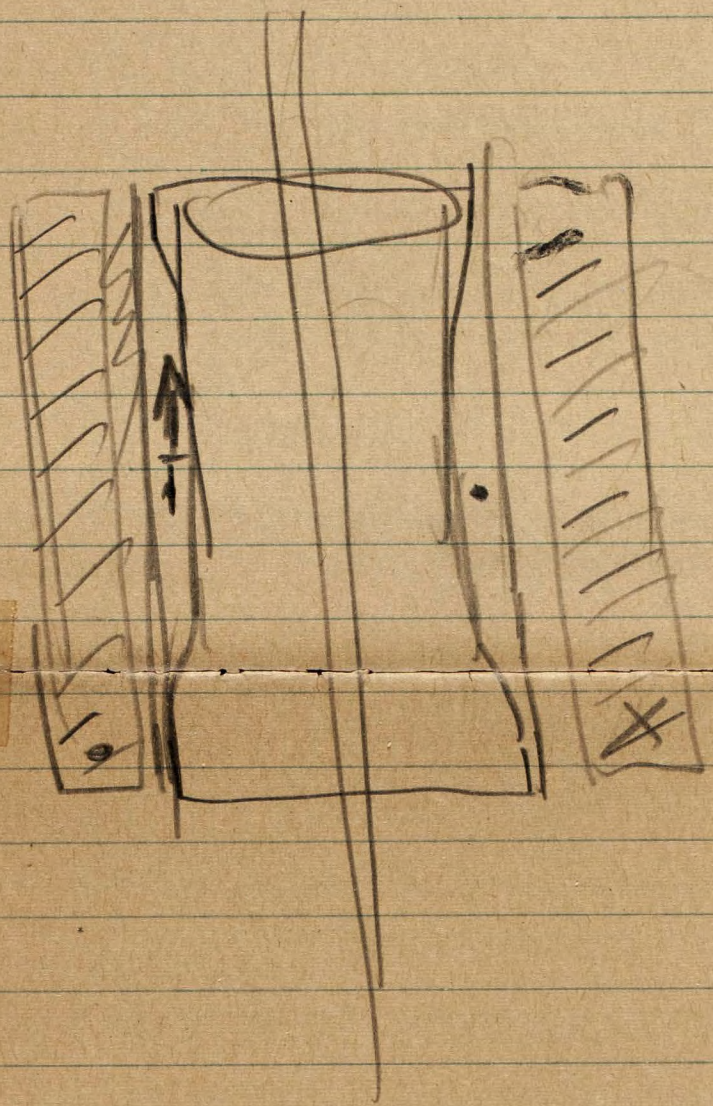
$H = 10$

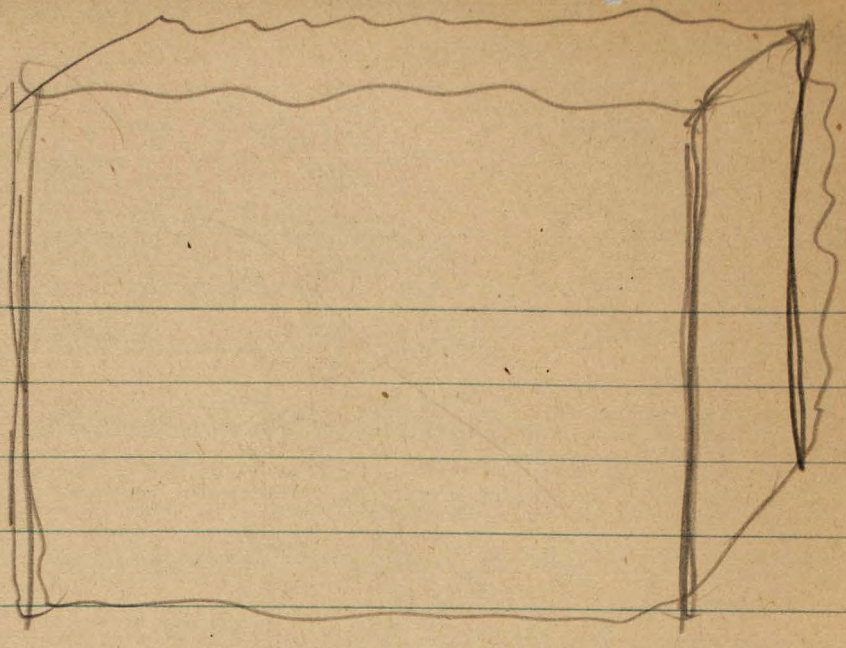
$$+ \frac{1}{R_1^3} \frac{n\rho}{\eta \frac{a}{\alpha}} + \text{etc.}$$

$R_3 = 6^4$

$R_2 = 5^4$

$R_1 = 4^4$





$\frac{20}{\frac{1}{2}}$ (40)

$2^* = 40$

8

Cultivation

mean free path

2 cm

Turbulence

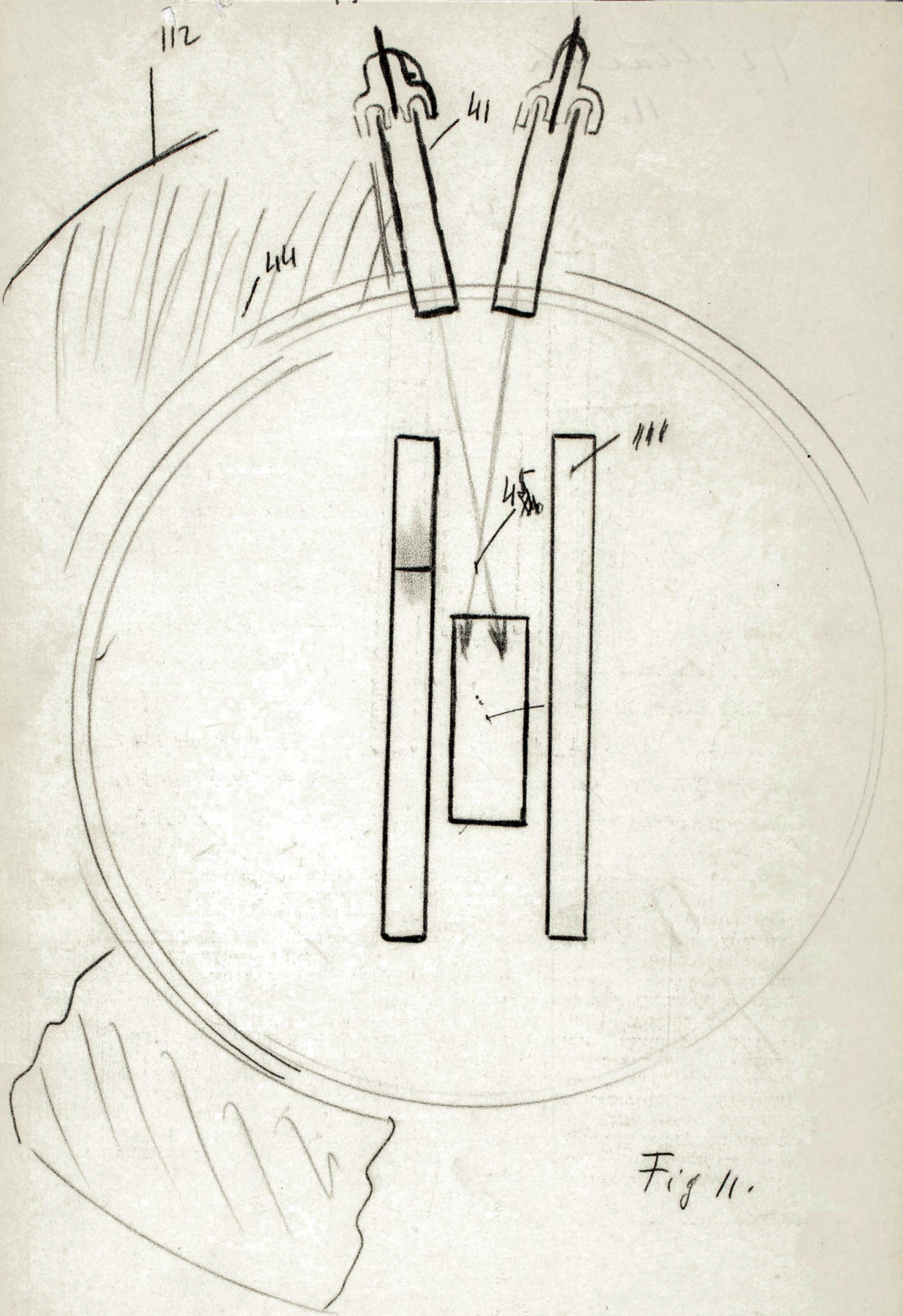


Fig 11.

12 March
11.

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 radio-active bodies. It is possible to produce with good efficiency radio-active bodies from various elements, if such elements are exposed to the penetrating radiation, the active agent of which are neutrons, that can be produced in various ways by means of electrical discharges. One way of generating such a neutron radiation consists in causing a nuclear reaction of hydrogen of the atomic weight 2 (diplogen) with itself or other light elements.

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 of gaseous 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 substance 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.

Other suitable arrangements are based on a different principle. The nuclear reaction of diplogen with itself for instance can be enforced by "heating up" diplogen through an electrical discharge for a fraction of a second. We can, for instance, store electrical energy by charging a condenser and then suddenly discharge the condenser through diplogen. We thus obtain a neutron radiation which can be used for the generation of radio-active bodies as above. Such devices for "heating up" will be described further below.

Such an arrangement is shown in Fig. 3. The discharge tube 41, 44 which contains diplogen is connected through a spark gap 51 to the condenser 52 which is intermittantly discharged through the diplogen. The condenser 52 is connected with a high voltage supply (D.C.) through the chokes 53, 54.

In order to ~~intxxxxxx~~ have a good efficiency the discharge tube has to be devised so as to introduce in a very short period of time a very large energy concentration in a small space filled with diplogen. One possibility of achieving this is by means of accelerating charged particles in a vacuum discharge tube and allowing them to go through the small space filled with diplogen.

Fig. 4 shows an illustration of the method. 41 is a discharge tube. 42 an electrode in this discharge tube. 43 a thin metal window hermetically sealing the vacuum in the discharge tube and allowing the passage of charged particles from the discharge tube into the interior of the vessel 44. A number of other discharge tubes similar to tube 41 can be placed around the vessel 44 in a position similar to that of 41, and all these tubes can be operated simultaneously. Each tube may have a separate set of electrical condensers and all these condensers may be discharged across the corresponding discharge tube simultaneously by using an electric impulse to bridge all the spark gaps simultaneously. The corpuscular rays of all the discharge tubes are focused on a small area 45 the "transmutation area" the volume of which is only a small fraction, e.g. ~~xx~~ ~~xxx~~ ~~xxxxx~~ ~~xx~~ of the volume of the vessel 44. The vacuum tubes may be operated as cathode ray tubes. Vacuum can be maintained in the interior of the vessel 44.

Up till now we have described the generation of radioactive bodies from elements which are transmuted by neutrons into radioactive bodies, by methods in which neutrons were

liberated in a nuclear reaction between light elements. The nuclear reactions between the light elements were brought about either by the bombardment of a target containing light elements with a beam of fast light atoms or by heating up a small space containing a light element. Now two further methods will be described for the liberation of the neutrons leading to the generation of radioactive bodies. One of these is based on the fact that neutrons can be liberated from certain elements, for instance beryllium, by X-rays.

Figure 5. shows an arrangement suitable for the production of hard X-rays. 1 is the primary of a transformer, the secondary 2 of 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 condensers 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 w[illegible]

with very good efficiency if it is built of Bi, Sb or some other heavy element.

England

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) atoms (or nuclei) and light elements,including heavy hydrogen (diplogen,also 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 elect ical 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 thivkness of the layer is of the order of magnitude of the mean free path of the neutron. ~~1 metre.~~ We have therefore two steps of good efficiency in series: the production of uncharged nucleiby 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 cathod 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:

CLAIMS

(1) In an apparatus for the production of radioactive elements I claim the combination of a device adapted to produce neutrons and a body (containing an element which transmutes into radioactive elements when interacting with neutrons exposed to the neutrons generated by the said device.

(2) In an apparatus for the production of radioactive bodies, according to Claim One, I claim the said device being the combination of a high voltage canal ray tube adapted for the generation of fast deutons or other light ions and deuterium or other light elements exposed to the said canal rays.

(3) In an apparatus for the production of radioactive bodies, according to Claim One, I claim the said device being the combination of a high voltage x-ray tube and an element from which neutrons are liberated by x-rays, for instance, beryllium exposed to the x-rays generated by the said tube.

(4) In an apparatus for the production of radioactive bodies, according to Claim One, I claim the said device being the combination of a high voltage electron tube and an element from which neutrons are liberated by fast electrons exposed to the cathode rays generated by the said tube.

(5) In an apparatus for the production of radioactive elements, according to Claim One, I claim the said body which is exposed to the ~~xxxxx~~ neutrons generated by the said device containing a chemical compound (of an element which transmutes into radioactive elements when inter-acting with neutrons) adapted for the chemical separation of the generated radioactive element from its non-radioactive isotope.

(6) In an apparatus for the production of radioactive elements, according to Claim One, I claim in the said device the combination of means for storing electrical energy, an electrical discharge tube adapted to produce a high energy concentration in a small space if the electrical energy stored by the said means is suddenly discharged ~~xxxxxx~~ through it, deuterium or mixtures of deuterium and other light elements in the said small space, means for discharging suddenly the stored energy through the said discharge tube.

(7) In an apparatus for the production of energy, I claim the combination of means for storing electrical energy, an electrical discharge tube adapted to produce a high energy concentration in a small

space if the electrical energy stored by the said means is suddenly discharged through it, deuterium or mixtures of deuterium or hydrogen with other light elements in the said small space means for discharging suddenly the stored energy through the said discharge tube, means for leading away and utilising the heat liberated in the transmutation process.

(8) In an apparatus for the production of radioactive elements or energy, I claim the combination of a device adapted to generate an initial radiation, for instance a neutron radiation, exposed to this radiation a body so composed that a chain reaction of neutrons be maintained.

(9) In an apparatus for the production of radioactive elements or energy, according to Claim 8, I claim the exposure of an element, which is transmuted into a radioactive element by neutrons, to the neutron radiation generated in the said body.

(10) In an apparatus for the production of radioactive elements or energy, according to Claim 8, I claim means for leading away the heat generatddgin the transmutation process, means for utilising the generated heat for power production.

(11) In an apparatus for the production of radioactive elements or energy, according to Claim 8, I claim the said body being so composed that a chain of heavy non-positive particles is maintained.

(12) In an apparatus for the production of radioactive elements or energy, according to Claim 11, I claim that the said body contains a metastable multiplicator.

(13) In an apparatus for the production of radioactive elements or energy, according to Claim 11, I claim that the said body contains a converter element, a reducer element, and a multiplicator.

(14) In an apparatus for the production of radioactive elements or energy, according to Claim 8, I claim that the said body contains beryllium.

(15) In an apparatus for the production of radioactive elements or energy, according to Claim 8, I claim that the said body be so composed that the chain in which neutrons and gygma particles alternate be maintained.

(16) In an apparatus for the production of radioactive elements or energy, according to Claim 15, I claim that said body contains an ele-

ment "K" which emits more than one sygma quanta for each captured neutron and one or more elements "L", "M" . . . which absorb strongly the sygma quanta emitted by "K" and eject neutrons in doing so.

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 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 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 a nuclear transmutation process leading to the liberation of neutrons being maintained through the action of xrays, 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 cathod 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) Methodx 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 ele - ments 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 the 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.