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PROVISIONAL SPECIFICATION
No. 7840 A.D. 1934.

Improvements in or relating to the Transmutation of Chemical Elements

I, LEO SZILARD, a citizen of Germany and Hungary, c/o Claremont Haynes & Co., Vernon House, Bloomsbury, Square, London, W.C.1, do hereby declare the nature of this invention to be as follows:—

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 these 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 ionizing 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 one still has to face the fact that a shooting particle has to travel for instance in air a large distance in order to encounter a nuclear collision (which may cause transmutation), but due to the energy loss which it suffers through ionizing the air its range is comparatively small if its initial velocity corresponds to several million volts energy. Only a fraction of the above mentioned shooting particles can therefore produce transmutation if shot into air or other substances or similar characteristics concerning ionization losses and nuclear collisions.

In accordance with the present invention radio-active bodies are generated by bombarding suitable elements with neutrons, which can be produced in various ways.

In accordance with one feature of the present invention nuclear transmutation leading to the liberation of neutrons and of energy may be brought about by heating up a small area filled with suitable elements very suddenly to high temperature by means of an electric discharge.

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, boron and magnesium with helium ions (particles). However, most of 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 ionization loss gets too large. It is, however, possible to produce with good efficiency (both from lighter and heavier elements) radio active sub-

[Price 1/-]

stances 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 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 gasous 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 gram per cubic cm.

If a substance X 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 grams 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 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 contains (after the exposure to the radiation) 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 70 elements in substance X do not contribute substantially to the radio active element which I want to produce and by eliminating those elements from the substance out of which I compose the layer. Such a measurement can be easily carried out by means of methods that are well-known in every physical laboratory.

These are the some features of this 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. I 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 might lead to a system of energy storage and such substances can be used as accumulators for driving cars, vessels, aeroplanes and so on. They would be indeed accumulators of a very small weight.

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 I 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. 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 I use an electric condenser to

store electrical energy and discharge this condenser in a fraction of a second across the discharge tube I can introduce (especially if I 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 " I can use protons or heavier ions or I can use cathode rays. I can easily estimate how much energy must be stored in the electric condenser in order to have a sufficient supply of energy to heat up sufficiently 1 cubic cm. of diplogen (an amount of diplogen that would fill 1 cubic cm. under ordinary pressure and temperature).

Fig. 2 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. Fig. 3 shows how the tube 41 is connected through a spark gap 51 to a condenser 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 " the volume of which is only a small fraction, e.g. of the order of one millionth to one thousandth of a millionth of the volume of the vessel 44. The ratio 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 the 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 I 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 I had a pressure of one atmos. before the discharge I 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 while the energy concentration is high in the transmutation area. 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.

One possible way of heating up electrically a definite area is 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 could theoretically heat up the transmutation area to anything between 100,000 to one billion degrees centigrade. 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 built for the purpose is able to stand a much higher voltage than it

would be able to stand for a longer time.

The following are some features of the described processes.

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.

A thick sheet of substance, for instance a 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.

In connection with point 2 the use of means for storing energy for the purpose of discharging a large amount of energy all of a sudden in a discharge tube; for instance such means as electric condensers.

Dated the 10th day of March, 1934.
LEO SZILARD.

PROVISIONAL SPECIFICATION
No. 33540 A.D. 1935.

Improvements in or relating to the Transmutation of Chemical Elements

I, LEO SZILARD, Citizen of Germany and 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 to be as follows:—

The invention relates to a process and to apparatus adapted for the generation of radio-active bodies by means of neutrons.

In accordance with the present invention neutrons are generated through the action of X-rays on matter or through the direct action of fast cathode rays on matter.

Neutrons are liberated from some elements, for instance Beryllium, if they are exposed in an electric discharge to the action of electrons. For instance if we expose them to the action of cathode rays of a couple of million volts neutrons are liberated from Beryllium.

Instead of exposing the substance which I wish to transmute to the direct action of the electron I shall in some cases expose it with advantage to the action of the X-rays which are generated if electrons travel through matter especially through heavy elements like Bi, Pb, Hg, Th, U etc.

Dated the 4th day of July, 1934.
CLAREMONT HAYNES & CO.,
Vernon House, Bloomsbury Square,
W.C.,
Applicant's Solicitors.

PROVISIONAL SPECIFICATION
No. 27050 A.D. 1934.

Improvements in or relating to the Transmutation of Chemical Elements

I, LEO SZILARD, a citizen of Germany, and 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 to be as follows:—

This invention has for its object the production of radio active bodies and the storage of energy through the production of such bodies.

In accordance with the present invention neutrons are liberated from matter by X-rays or fast cathode rays, for instance from Beryllium.

In accordance with one feature of this invention radio active bodies are generated by means of these neutrons.

In accordance with another feature of this invention the radio active element which is produced by means of neutrons

which are generated in this or in some other way is separated from its bombarded isotope by being produced through the irradiation of a chemical compound of the element which chemical compound does not exchange the atoms of this element within the compound against the atoms of the same element outside the compound.

Radio-active bodies can be generated by bombarding certain elements with neutrons from a Radon-α-Ray Beryllium source. The process involved is of different type in different elements. Some elements transmute when bombarded by such neutrons into a radio-active element which has an atomic number lower than the original element. I conclude that such a transmutation is not possible, if heavy elements are bombarded by slow neutrons. I conclude this for the following reason:—if in the primary process which leads to the formation of a radio-active atom, the neutron disappears and a proton or an alpha particle or another positive nucleus is ejected, one gets a radio-active atom, the chemical properties of which are different from the original atom as the atomic number of the new element is lower. I predict that such a process will not take place if the energy of the neutron and the atomic number of the bombarded element are such that the positive particles which were to be ejected could not penetrate against the Coulomb field in the inverse process. Therefore I predict that if I induce radio-activity by slow neutrons, (as for instance the neutrons generated by the bombardment of Diplogen by Diplogen canal rays of less than a million volt energy) in heavy elements, the new element will have no lower atomic number than the original element. Such induced activities in some heavy elements with slow neutrons have been observed to be processes of good efficiency. As a change in atomic number does not occur I conclude that there is a change in the mass number of the bombarded element, and I predict that in the known cases the change consists not in a decrease but in an increase of the mass number. I can further predict that a radiation subsequently called sygma radiation is emitted by such elements (i.e. by elements which show no chemical change, but show an induced activity having the same chemical properties as the original elements when bombarded by neutrons as for instance, iodine, arsenic, gold, bromine, rhodium, iridium etc.) when bombarded by neutrons. This sygma radiation carries away the excess energy liberated in the process of the capture of the bombarding neutron. A fraction of this sygma radiation consists of "hard X-rays," but I wish to leave it open what portion of the sygma radiation consists of "hard X-rays" and this fraction might vary from element to element. I further predict that the sygma radiation can liberate neutrons from certain elements and also "hard X-rays" can do so. Further a similar action can be exercised by fast electrons in processes in which the fast electron is not captured. They can further produce radio-active bodies indirect (and this is most important) by ejecting from an element neutrons which generate radio-active bodies in the same element or in another element mixed with the first element, or exposed to the radiation of the first element.

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

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

Certain "mixtures" of two or more elements will show an action of the X-rays or cathode rays of the following type:—neutrons will be emitted by one of the components of the mixture under the influence of the "hard X-rays" and another component of the mixture will transmute into a radio-active body under the influence of the said neutral radiation.

Examples are combinations of an element like Beryllium which yields neutrons under the influence of "hard X-rays" with other elements, especially with such elements which show an induced activity when bombarded by neutrons without showing a chemical change in the process. Such elements can be selected either by radiating the elements mentioned above one by one with a Radon-α Ray Beryllium neutron source and investigating the chemical properties of the induced activity or alternatively by radiating the elements one by one with slow neutrons and selecting those elements which show an induced activity under the influence of slow neutrons. Slow neutrons can for the purpose of this investigation be generated by bombarding Fluorine with a Radon-α Ray source or by bombarding Diplogen with Diplogen canal rays). If I produce radio-active bodies by irradiating one of those

elements which, like iodine, transmute into their own radioactive isotope, it requires a special method chemically to separate the radioactive element from its irradiated isotope. According to the invention I can achieve such a separation by irradiating a chemical compound of the said element. Those atoms of our element which transmute into a radioactive atom are thrown out of the compound and will subsequently be called "free." If I 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 isotope, we can chemically separate the "free" atoms from the compound and thereby separate the radioactive isotope from the irradiated element. Compounds in which the element in which we are interested are bound direct to carbon are very often suitable. For instance in the case of iodine compounds like iodoform or ethyl iodide can be irradiated and after irradiation the radio-active isotope can be concentrated by separating the "free" iodine from the iodoform or the ethyl iodide. In order to protect radioactive iodine a small amount of ordinary iodine can be dissolved in the organic iodine compound before irradiation or after irradiation but before separation.

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

An impulse generator is adapted to produce intermittent voltage up to 10 million volts, which can be transmitted to cathode of a discharge tube through the spark gap, the anode of which is connected to the earth. The fast electrons can emerge through the metal window (which is connected to the anode) and are hitting a body used as an anticathode which yields "hard X-rays" with very good efficiency if it is built of Bi, Pb or some other heavy element. If the anticathode is surrounded by a thick sheet containing some of the elements radioactive bodies are generated in this sheet.

The generation of radio-active bodies is due to different types of action, mentioned above.

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

In Figure 1 of the accompanying drawing, 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. × 25 cm. × 25 cm. The voltage used to operate the electron tube may be three million volt. The beryllium block is surrounded by a block 34 of the element which I wish to transmute into a radioactive element, for instance, iodine, or arsenic or any other element that is suitable. While it is advisable to use metallic beryllium in the block 52 the element in the block 34 may be present in the form of an organic compound in order to make an isotopic separation possible after irradiation. The dimensions of block 34 may for instance be 50 cm. × 50 cm. × 50 cm.

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

Since the output is within certain limits proportionate to the thickness of material which the X-rays have to travel in beryllium, and also to the thickness of material which the rays emitted by the beryllium have to travel in the material in which I wish to induce radioactivity it is essential to choose the dimensions both of the beryllium and of the material which we wish to activate. If I have only a limited amount of the material which I wish to activate (limited from the point of view of keeping down the capital investment and the waste of material which accompanies the chemical separation of the radioactive material) it may be advisable to reverse the arrangement shown in Figure 2 in the following way: 34 the outer block should be made of beryllium and 52 the inner block should be made of the material which I wish to activate.

Fast electrons have a similar action on beryllium as hard X-rays, a fraction of this action may be due to the generation of hard X-rays in the beryllium but another fraction may be due to the direct action of the fast electrons on the beryllium. In view of the fact that hard X-rays generate fast electrons in the beryllium, part of their action might be due to fast electrons. In any case I do not wish to differentiate here between the action of fast electrons and hard X-rays, and while I think that the direct action of hard X-rays on the beryllium plays the major part in the liberation of neutrons I 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 coating 31 of the rotating anticathode 30 in Figure 2.

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

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

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

Dated this 20th day of September, 1934.
LEO SZILARD.

COMPLETE SPECIFICATION

Improvements in or relating to the Transmutation of Chemical Elements

I, LEO SZILARD, a citizen of Germany, and 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.

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 radioactive elements are generated by 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.

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.

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 natural radio active elements, but including uranium and thorium (from which the beta active products have been removed) and exposes the 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.

The following are the essential features of one method for the production of radio active substances according to the present invention. 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 particles 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 or larger. I 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 can be 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.

The technique for carrying out this method described in connection with Fig. 2 was 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. Another technique for carrying out this method is described in the following.

If one maintains 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. 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 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.

The neutron radiation generated by bringing diplogen into nuclear reaction with itself through heating it up with an electric discharge can be utilised for the generation of radio active bodies as described above.

Fig. 3 illustrates the technique of generating neutrons by heating up suddenly diplogen with an electric discharge. In Fig. 3 52 is an electrical condenser which is charged up through the chokes 53 and 54 to a high electrical potential. When the potential reaches a critical value the electrical energy stored in this condenser is suddenly discharged

through the spark gap 51 (which is connected to the cathode 42) and the discharge tube 41 which contains diplogen.

One possible form of the discharge tube 41 is shown in Fig. 4. In Fig. 4 the discharge tube 41 takes the form of a cathode ray tube. 52 is an electrical condenser which is charged up through the chokes 53 and 54 to a high electrical potential. When the potential reaches a critical value the electrical energy stored in this condenser is suddenly discharged through the spark gap 51 (which is connected to the cathode 42) and the cathode ray tube 41. A thin metal window hermetically seals off the vacuum in the cathode ray tube 41 but allows the passage of the cathode rays from the discharge tube 41 into the interior of a spherical container in the centre of which is placed a small container 44. The corpuscular rays generated by one or more such cathode ray tubes are focused on this small container 44 which may contain diplogen.

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 cathode 13 and 14 are connected to each other and to earth. The anode 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 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 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 axle 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 25cm. × 25cm. × 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. × 50cm. × 50cm.

Fast electrons have a similar action on beryllium to 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, I do not wish to differentiate here between the action of fast electrons and hard X-rays, and while I think it likely that the direct action of hard X-rays on the beryllium plays the major part in the liberation of neutrons, I wish to envisage the following modification of my method: The electrons of the discharge tube fall instead of on lead on beryllium which can be put into the place of the lead coating 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. One can achieve such a separation by irradiating a suitable chemical compound of the said element. Those atoms of this element which transmute into a radio active atom are thrown out of the compound and will subsequently be called "free." If one chooses a compound which in the circumstances does not interchange the atoms of this element bound within the compound with the "free" atoms which are their isotopes one 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, the radio active isotope of which one wants to separate, is bound direct to carbon are often very suitable. For instance, in the case of iodine compounds like iodoform or ethyl iodide can be irradiated and after irradiation the radioactive 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.

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 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 according to Claim 1 characterised 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 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 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 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 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 for the generation of radioactive elements according to Claim 1, characterized by the exposure of an element in the form of a chemical compound to the said neutron radiation, which element transmutes into its own radioactive isotope, the compound being chosen for the separation of the radioactive element from its non-radioactive isotope.

8. A method of generating radioactive elements substantially as hereinbefore described with reference to the accompanying drawings.

9. Apparatus when used for carrying out the methods claimed in any of the Claims 1 to 8, substantially as described with reference to the accompanying drawings.

Dated the 9th day of April, 1935.

CLAREMONT HAYES & CO.,
Vernon House, Sicilian Avenue,
Bloomsbury Square, W.C.1,
Applicant's Solicitors.

Leamington Spa: Printed for His Majesty's Stationery Office, by the Courier Press.—1936.

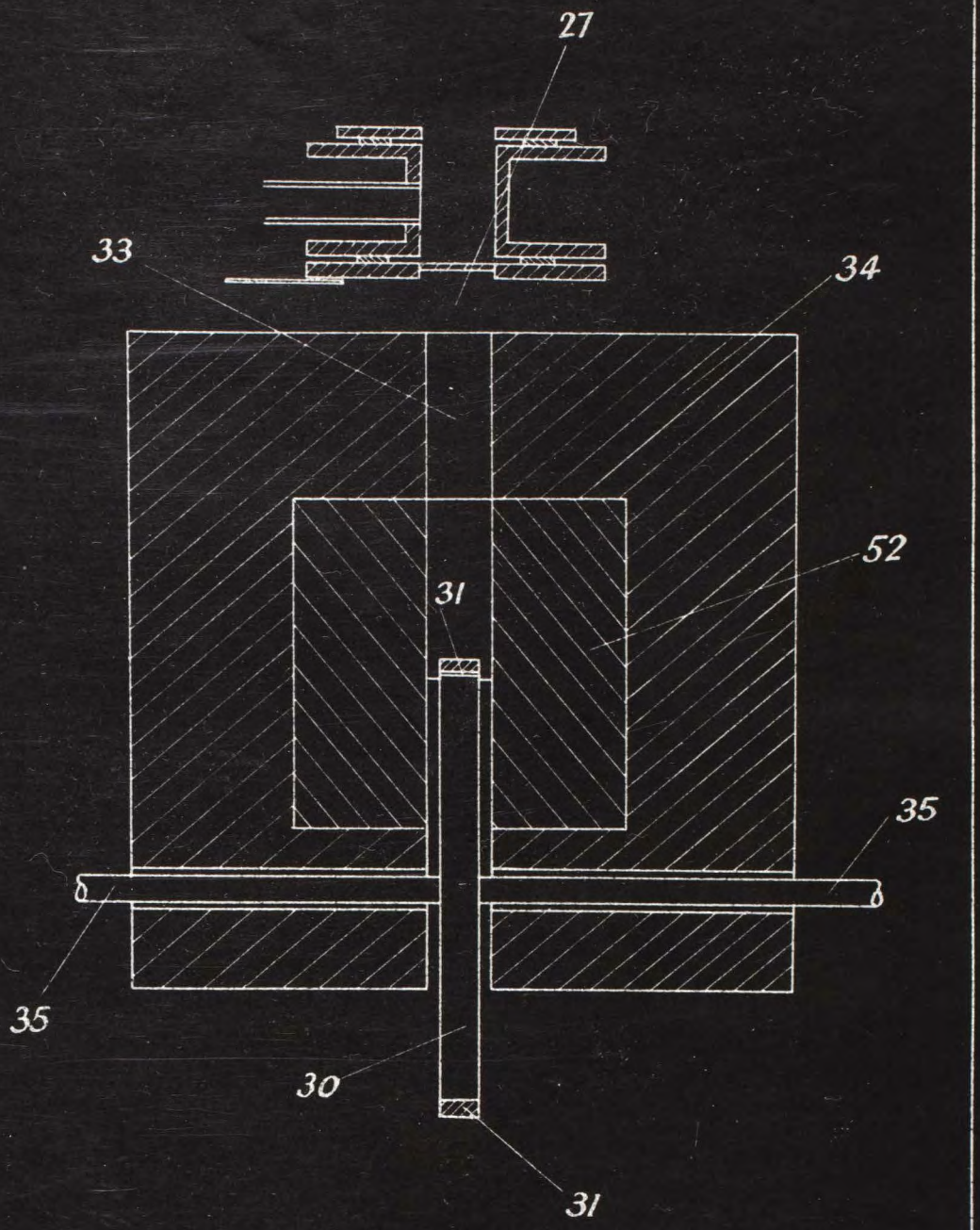

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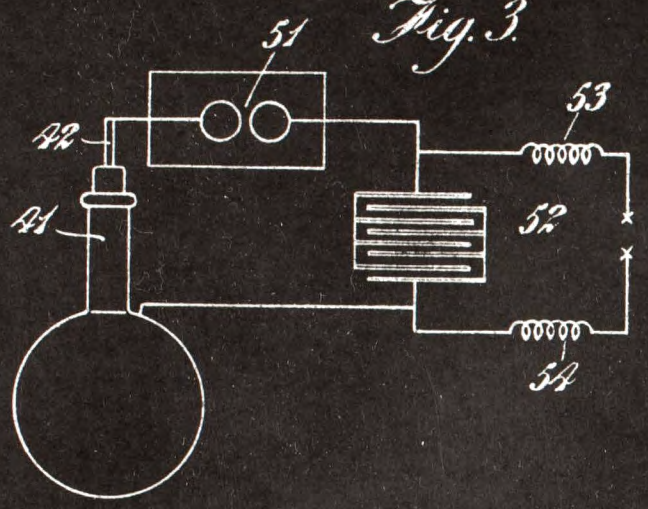
Fig. 3.



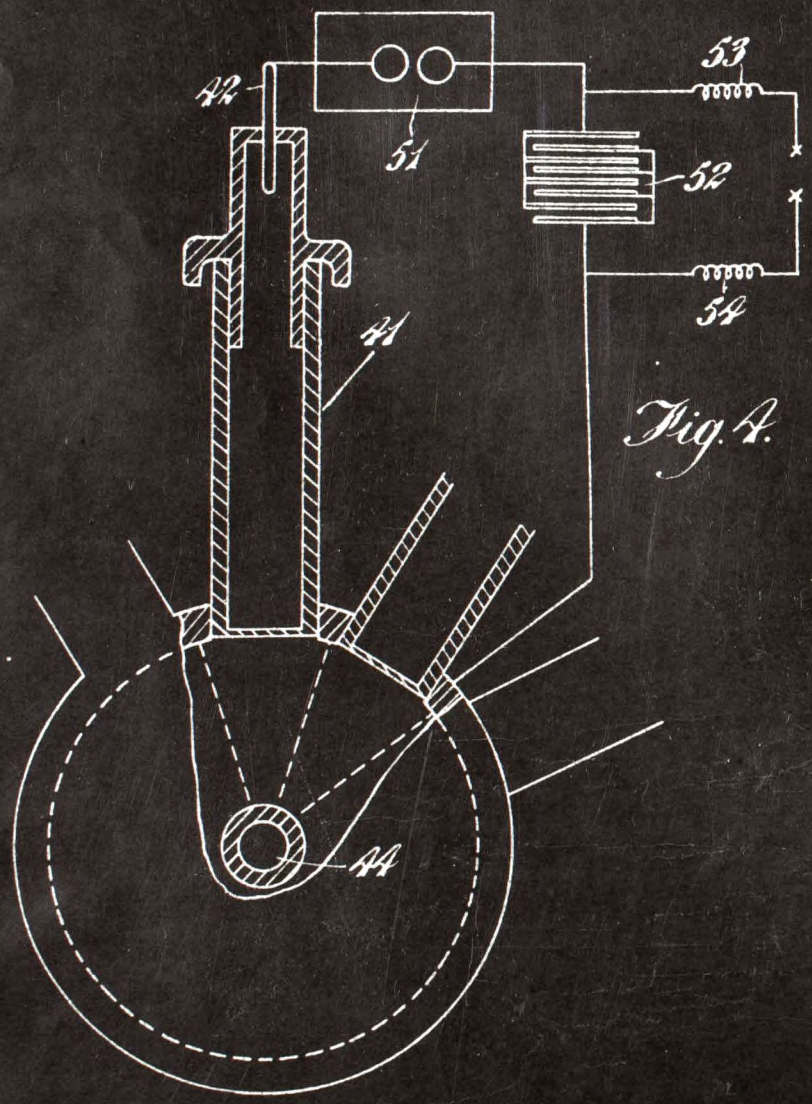


Fig. 4.

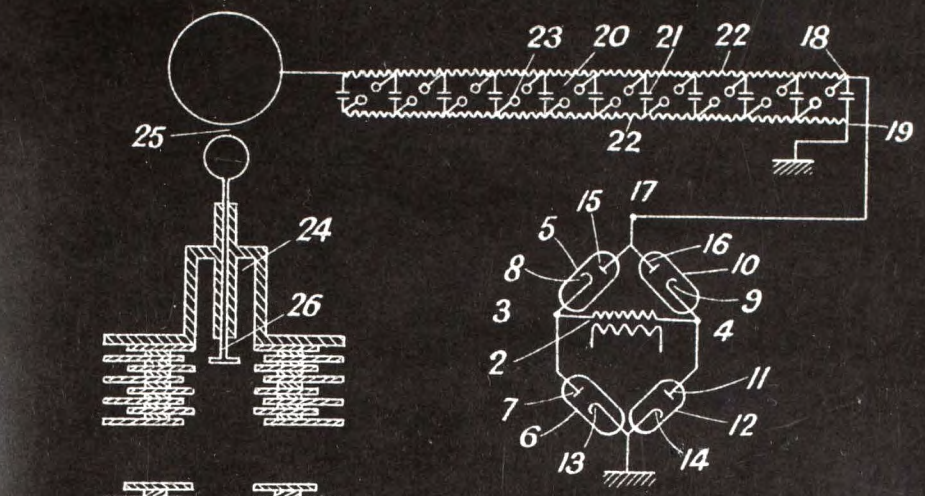
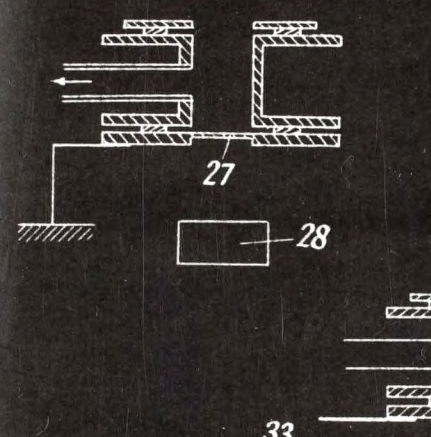
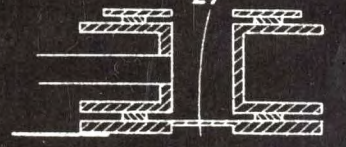


FIG. 5.





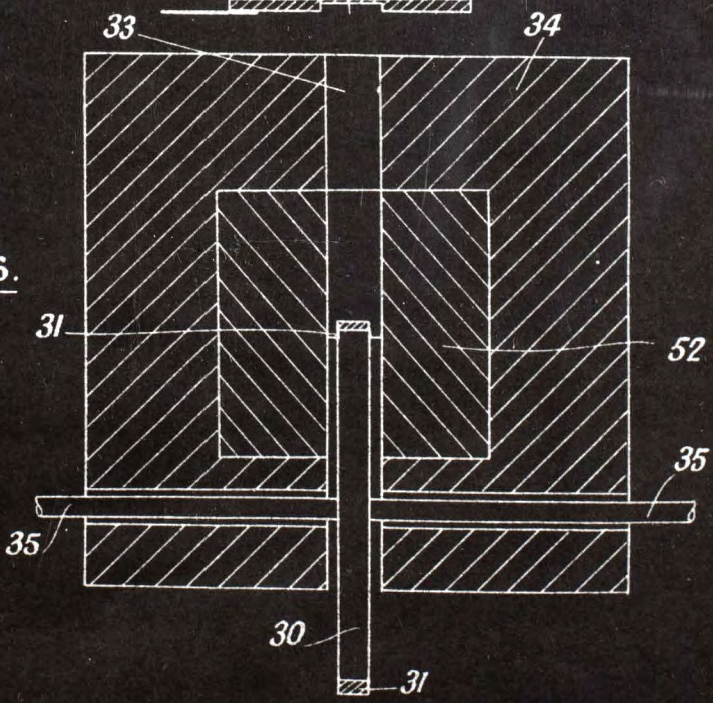


FIG. 6.

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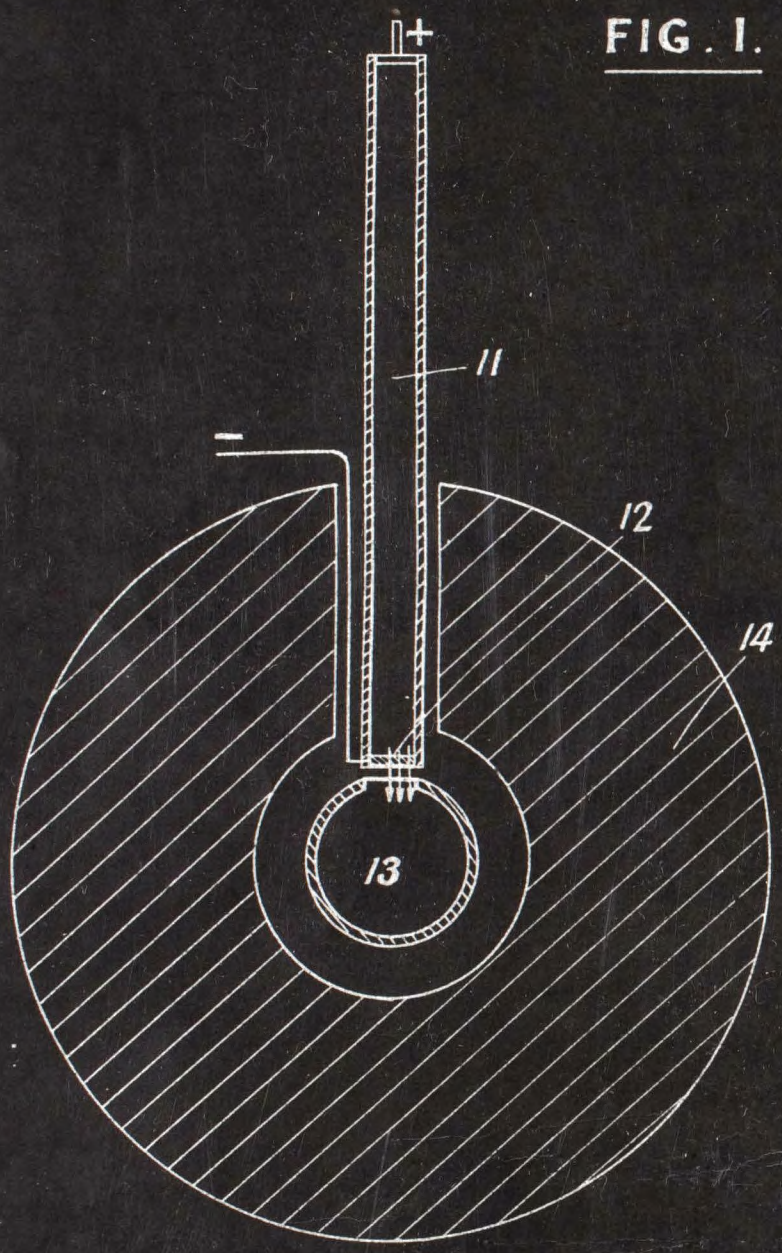
[This Drawing is a reproduction of the Original on a reduced scale.]

FIG. 1.



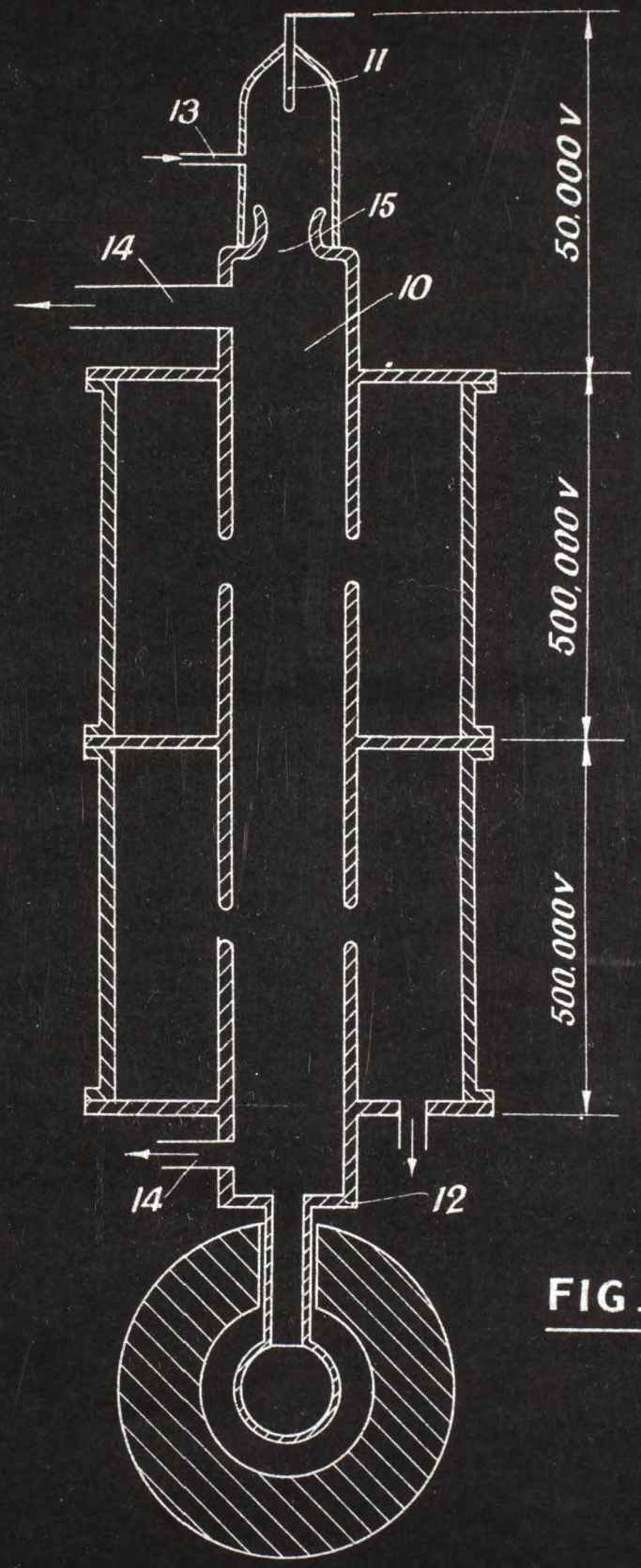


FIG. 2

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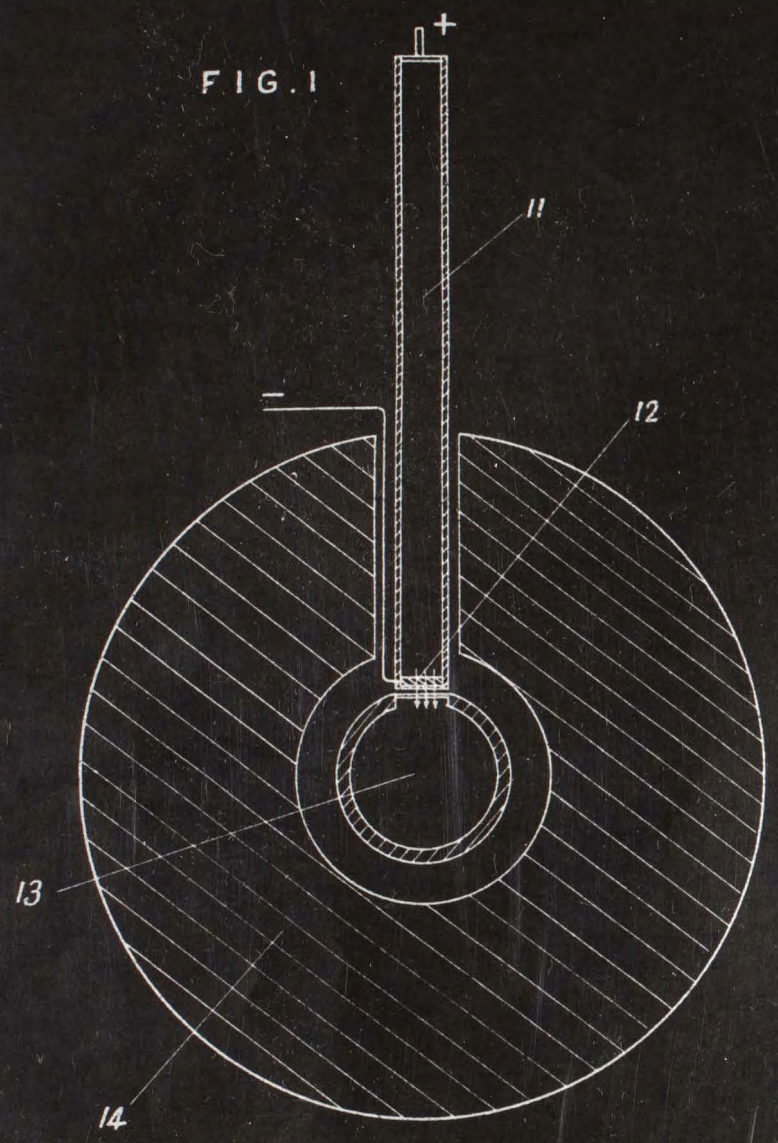
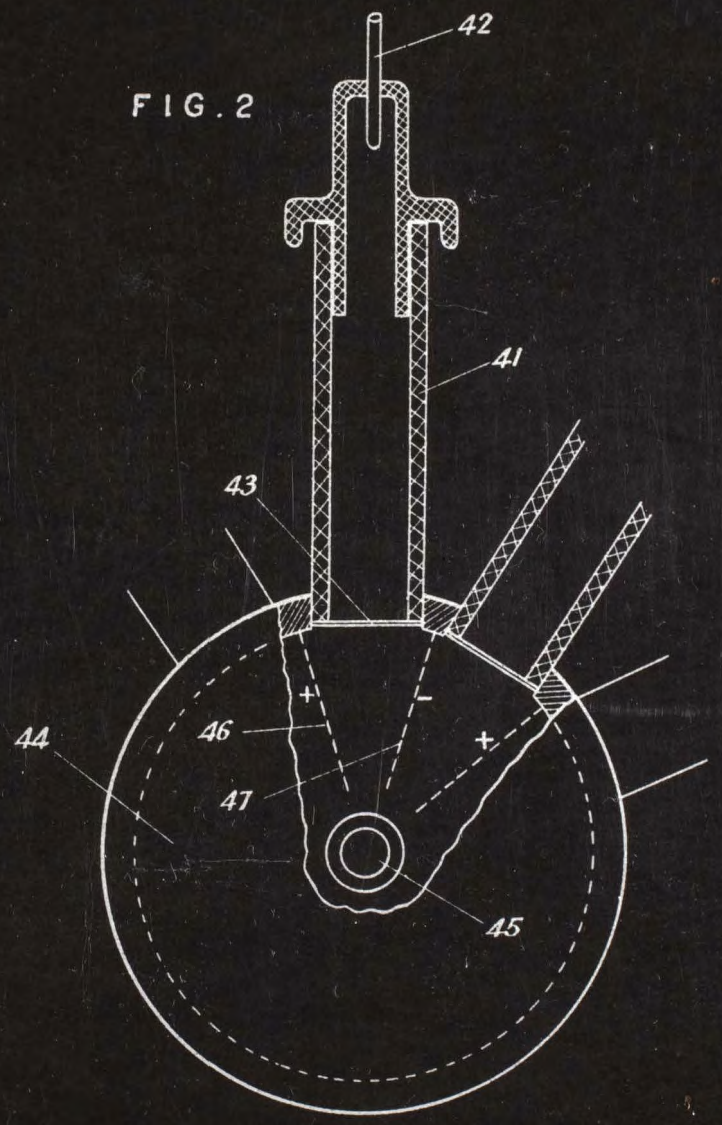
SHEET 1

FIG. 1



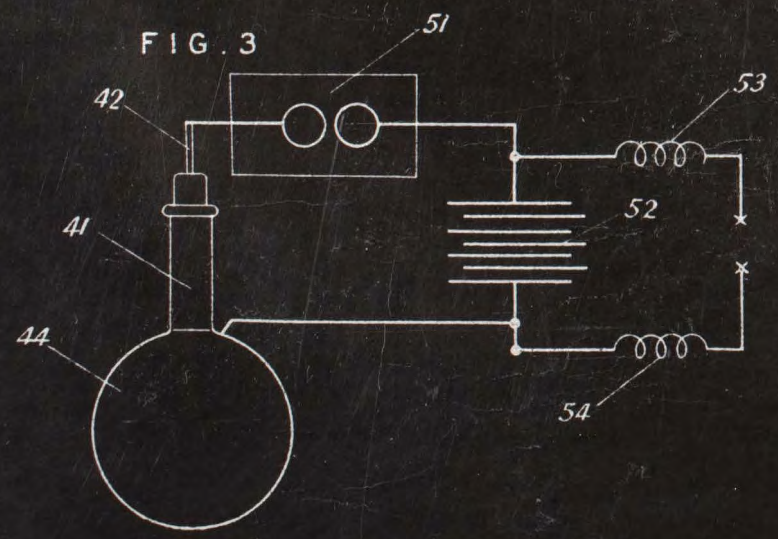
SHEET 2

FIG. 2



SHEET 3

FIG. 3



[This Drawing is a reproduction of the Original on a reduced scale.]

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PATENT SPECIFICATION

440,023

Application Date: March 12, 1934. No. 7840/34.
" " July 4, 1934. No. 33540/35.
(No. 33540/35 being divided out of Application No. 19721/34.)
Application Date: Sept. 20, 1934. No. 27050/34.
One Complete Specification Left: April 9, 1935.
(Under Section 16 of the Patents and Designs Acts, 1907 to 1932.)
Specification Accepted: Dec. 12, 1935.

PROVISIONAL SPECIFICATION
No. 7840 A.D. 1934.

Improvements in or relating to the Transmutation of Chemical Elements

I, LEO SZILARD, a citizen of Germany and Hungary, c/o Claremont Haynes & Co., Vernon House, Bloomsbury, Square, London, W.C.1, do hereby declare the nature of this invention to be as follows:—

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 these 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 ionizing 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 [illegible] 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 one still has to face the fact that a shooting particle has to travel for instance in air a large distance in order to encounter a nuclear collision (which may cause transmutation), but due to the energy loss which it suffers through ionizing the air its range is comparatively small if its initial velocity corresponds to several million volts energy. Only a fraction of the above mentioned shooting particles can therefore produce transmutation if shot into air or other substances or similar characteristics concerning ionization losses and nuclear collisions.

In accordance with the present invention radio-active bodies are generated by bombarding suitable elements with neutrons, which can be produced in various ways.

In accordance with one feature of the present invention nuclear transmutation leading to the liberation of neutrons and of energy may be brought about by heating up a small area filled with suitable elements very suddenly to high temperature by means of an electric discharge.

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, boron and magnesium with helium ions (particles). However, most of 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 ionization loss gets too large. It is, however, possible to produce with good efficiency (both from lighter and heavier elements) radio active sub-

[Price 1/-]

stances 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 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 gasous 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 gram per cubic cm.

If a substance X 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 grams 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 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 contains (after the exposure to the radiation) 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 70 elements in substance X do not contribute substantially to the radio active element which I want to produce and by eliminating those elements from the substance out of which I compose the layer. Such a measurement can be easily carried out by means of methods that are well-known in every physical laboratory.

These are the some features of this 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. I 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 might lead to a system of energy storage and such substances can be used as accumulators for driving cars, vessels, aeroplanes and so on. They would be indeed accumulators of a very small weight.

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 I were to maintain a very large concentration of energy in a space filled 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. 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 I use an electric condenser to

store electrical energy and discharge this condenser in a fraction of a second across the discharge tube I can introduce (especially if I 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 " I can use protons or heavier ions or I can use cathode rays. I can easily estimate how much energy must be stored in the electric condenser in order to have a sufficient supply of energy to heat up sufficiently 1 cubic cm. of diplogen (an amount of diplogen that would fill 1 cubic cm. under ordinary pressure and temperature).

Fig. 2 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. Fig. 3 shows how the tube 41 is connected through a spark gap 51 to a condenser 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 " the volume of which is only a small fraction, e.g. of the order of one millionth to one thousandth of a millionth of the volume of the vessel 44. The ratio 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 the 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 I 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 I had a pressure of one atmos. before the discharge I 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 while the energy concentration is high in the transmutation area. 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.

One possible way of heating up electrically a definite area is 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 could theoretically heat up the transmutation area to anything between 100,000 to one billion degrees centigrade. 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 built for the purpose is able to stand a much higher voltage than it

would be able to stand for a longer time.

The following are some features of the described processes.

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.

A thick sheet of substance, for instance a 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.

In connection with point 2 the use of means for storing energy for the purpose of discharging a large amount of energy all of a sudden in a discharge tube; for instance such means as electric condensers.

Dated the 10th day of March, 1934.
LEO SZILARD.

PROVISIONAL SPECIFICATION
No. 33540 A.D. 1935.

Improvements in or relating to the Transmutation of Chemical Elements

I, LEO SZILARD, Citizen of Germany and 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 to be as follows:—

The invention relates to a process and to apparatus adapted for the generation of radio-active bodies by means of neutrons.

In accordance with the present invention neutrons are generated through the action of X-rays on matter or through the direct action of fast cathode rays on matter.

Neutrons are liberated from some elements, for instance Beryllium, if they are exposed in an electric discharge to the action of electrons. For instance if we expose them to the action of cathode rays of a couple of million volts neutrons are liberated from Beryllium.

Instead of exposing the substance which I wish to transmute to the direct action of the electron I shall in some cases expose it with advantage to the action of the X-rays which are generated if electrons travel through matter especially through heavy elements like Bi, Pb, Hg, Th, U etc.

Dated the 4th day of July, 1934.
CLAREMONT HAYNES & CO.,
Vernon House, Bloomsbury Square,
W.C.,
Applicant's Solicitors.

PROVISIONAL SPECIFICATION
No. 27050 A.D. 1934.

Improvements in or relating to the Transmutation of Chemical Elements

I, LEO SZILARD, a citizen of Germany, and 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 to be as follows:—

This invention has for its object the production of radio active bodies and the storage of energy through the production of such bodies.

In accordance with the present invention neutrons are liberated from matter by X-rays or fast cathode rays, for instance from Beryllium.

In accordance with one feature of this invention radio active bodies are generated by means of these neutrons.

In accordance with another feature of this invention the radio active element which is produced by means of neutrons

which are generated in this or in some other way is separated from its bombarded isotope by being produced through the irradiation of a chemical compound of the element which chemical compound does not exchange the atoms of this element within the compound against the atoms of the same element outside the compound.

Radio-active bodies can be generated by bombarding certain elements with neutrons from a Radon-α-Ray Beryllium source. The process involved is of different type in different elements. Some elements transmute when bombarded by such neutrons into a radio-active element which has an atomic number lower than the original element. I conclude that such a transmutation is not possible, if heavy elements are bombarded by slow neutrons. I conclude this for the following reason:—if in the primary process which leads to the formation of a radio-active atom, the neutron disappears and a proton or an alpha particle or another positive nucleus is ejected, one gets a radio-active atom, the chemical properties of which are different from the original atom as the atomic number of the new element is lower. I predict that such a process will not take place if the energy of the neutron and the atomic number of the bombarded element are such that the positive particles which were to be ejected could not penetrate against the Coulomb field in the inverse process. Therefore I predict that if I induce radio-activity by slow neutrons, (as for instance the neutrons generated by the bombardment of Diplogen by Diplogen canal rays of less than a million volt energy) in heavy elements, the new element will have no lower atomic number than the original element. Such induced activities in some heavy elements with slow neutrons have been observed to be processes of good efficiency. As a change in atomic number does not occur I conclude that there is a change in the mass number of the bombarded element, and I predict that in the known cases the change consists not in a decrease but in an increase of the mass number. I can further predict that a radiation subsequently called sygma radiation is emitted by such elements (i.e. by elements which show no chemical change, but show an induced activity having the same chemical properties as the original elements when bombarded by neutrons as for instance, iodine, arsenic, gold, bromine, rhodium, iridium etc.) when bombarded by neutrons. This sygma radiation carries away the excess energy liberated in the process of the capture of the bombarding neutron. A fraction of this sygma radiation consists of "hard X-rays," but I wish to leave it open what portion of the sygma radiation consists of "hard X-rays" and this fraction might vary from element to element. I further predict that the sygma radiation can liberate neutrons from certain elements and also "hard X-rays" can do so. Further a similar action can be exercised by fast electrons in processes in which the fast electron is not captured. They can further produce radio-active bodies indirect (and this is most important) by ejecting from an element neutrons which generate radio-active bodies in the same element or in another element mixed with the first element, or exposed to the radiation of the first element.

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

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

Certain "mixtures" of two or more elements will show an action of the X-rays or cathode rays of the following type:—neutrons will be emitted by one of the components of the mixture under the influence of the "hard X-rays" and another component of the mixture will transmute into a radio-active body under the influence of the said neutral radiation.

Examples are combinations of an element like Beryllium which yields neutrons under the influence of "hard X-rays" with other elements, especially with such elements which show an induced activity when bombarded by neutrons without showing a chemical change in the process. Such elements can be selected either by radiating the elements mentioned above one by one with a Radon-α Ray Beryllium neutron source and investigating the chemical properties of the induced activity or alternatively by radiating the elements one by one with slow neutrons and selecting those elements which show an induced activity under the influence of slow neutrons. Slow neutrons can for the purpose of this investigation be generated by bombarding Fluorine with a Radon-α Ray source or by bombarding Diplogen with Diplogen canal rays). If I produce radio-active bodies by irradiating one of those

elements which, like iodine, transmute into their own radioactive isotope, it requires a special method chemically to separate the radioactive element from its irradiated isotope. According to the invention I can achieve such a separation by irradiating a chemical compound of the said element. Those atoms of our element which transmute into a radioactive atom are thrown out of the compound and will subsequently be called "free." If I 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 isotope, we can chemically separate the "free" atoms from the compound and thereby separate the radioactive isotope from the irradiated element. Compounds in which the element in which we are interested are bound direct to carbon are very often suitable. For instance in the case of iodine compounds like iodoform or ethyl iodide can be irradiated and after irradiation the radio-active isotope can be concentrated by separating the "free" iodine from the iodoform or the ethyl iodide. In order to protect radioactive iodine a small amount of ordinary iodine can be dissolved in the organic iodine compound before irradiation or after irradiation but before separation.

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

An impulse generator is adapted to produce intermittent voltage up to 10 million volts, which can be transmitted to cathode of a discharge tube through the spark gap, the anode of which is connected to the earth. The fast electrons can emerge through the metal window (which is connected to the anode) and are hitting a body used as an anticathode which yields "hard X-rays" with very good efficiency if it is built of Bi, Pb or some other heavy element. If the anticathode is surrounded by a thick sheet containing some of the elements radioactive bodies are generated in this sheet.

The generation of radio-active bodies is due to different types of action, mentioned above.

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

In Figure 1 of the accompanying drawing, 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. × 25 cm. × 25 cm. The voltage used to operate the electron tube may be three million volt. The beryllium block is surrounded by a block 34 of the element which I wish to transmute into a radioactive element, for instance, iodine, or arsenic or any other element that is suitable. While it is advisable to use metallic beryllium in the block 52 the element in the block 34 may be present in the form of an organic compound in order to make an isotopic separation possible after irradiation. The dimensions of block 34 may for instance be 50 cm. × 50 cm. × 50 cm.

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

Since the output is within certain limits proportionate to the thickness of material which the X-rays have to travel in beryllium, and also to the thickness of material which the rays emitted by the beryllium have to travel in the material in which I wish to induce radioactivity, it is essential to choose the dimensions both of the beryllium and of the material which we wish to activate. If I have only a limited amount of the material which I wish to activate (limited from the point of view of keeping down the capital investment and the waste of material which accompanies the chemical separation of the radioactive material) it may be advisable to reverse the arrangement shown in Figure 2 in the following way: 34 the outer block should be made of beryllium and 52 the inner block should be made of the material which I wish to activate.

Fast electrons have a similar action on beryllium as hard X-rays, a fraction of this action may be due to the generation of hard X-rays in the beryllium but another fraction may be due to the direct action of the fast electrons on the beryllium. In view of the fact that hard X-rays generate fast electrons in the beryllium, part of their action might be due to fast electrons. In any case I do not wish to differentiate here between the action of fast electrons and hard X-rays, and while I think that the direct action of hard X-rays on the beryllium plays the major part in the liberation of neutrons I 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 coating 31 of the rotating anticathode 30 in Figure 2.

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

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

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

Dated this 20th day of September, 1934.
LEO SZILARD.

COMPLETE SPECIFICATION

Improvements in or relating to the Transmutation of Chemical Elements

I, LEO SZILARD, a citizen of Germany, and 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.

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 radioactive elements are generated by 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.

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.

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 natural radio active elements, but including uranium and thorium (from which the beta active products have been removed) and exposes the 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.

The following are the essential features of one method for the production of radio active substances according to the present invention. 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 particles 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 or larger. I 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 can be 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.

The technique for carrying out this method described in connection with Fig. 2 was 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. Another technique for carrying out this method is described in the following.

If one maintains 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. 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 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.

The neutron radiation generated by bringing diplogen into nuclear reaction with itself through heating it up with an electric discharge can be utilised for the generation of radio active bodies as described above.

Fig. 3 illustrates the technique of generating neutrons by heating up suddenly diplogen with an electric discharge. In Fig. 3 52 is an electrical condenser which is charged up through the chokes 53 and 54 to a high electrical potential. When the potential reaches a critical value the electrical energy stored in this condenser is suddenly discharged

through the spark gap 51 (which is connected to the cathode 42) and the discharge tube 41 which contains diplogen.

One possible form of the discharge tube 41 is shown in Fig. 4. In Fig. 4 the discharge tube 41 takes the form of a cathode ray tube. 52 is an electrical condenser which is charged up through the chokes 53 and 54 to a high electrical potential. When the potential reaches a critical value the electrical energy stored in this condenser is suddenly discharged through the spark gap 51 (which is connected to the cathode 42) and the cathode ray tube 41. A thin metal window hermetically seals off the vacuum in the cathode ray tube 41 but allows the passage of the cathode rays from the discharge tube 41 into the interior of a spherical container in the centre of which is placed a small container 44. The corpuscular rays generated by one or more such cathode ray tubes are focused on this small container 44 which may contain diplogen.

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 cathode 13 and 14 are connected to each other and to earth. The anode 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 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 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 axle 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 25cm. × 25cm. × 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. × 50cm. × 50cm.

Fast electrons have a similar action on beryllium to 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, I do not wish to differentiate here between the action of fast electrons and hard X-rays, and while I think it likely that the direct action of hard X-rays on the beryllium plays the major part in the liberation of neutrons, I wish to envisage the following modification of my method: The electrons of the discharge tube fall instead of on lead on beryllium which can be put into the place of the lead coating 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. One can achieve such a separation by irradiating a suitable chemical compound of the said element. Those atoms of this element which transmute into a radio active atom are thrown out of the compound and will subsequently be called "free." If one chooses a compound which in the circumstances does not interchange the atoms of this element bound within the compound with the "free" atoms which are their isotopes one 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, the radio active isotope of which one wants to separate, is bound direct to carbon are often 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.

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 for the generation of radio-active 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 radio-active element under the influence of the said neutron radiation.

2. A method according to Claim 1 characterised 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 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 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 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 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 for the generation of radio-active elements according to Claim 1, characterized by the exposure of an element in the form of a chemical compound to the said neutron radiation, which element transmutes into its own radio-active isotope, the compound being chosen for the separation of the radio-active element from its non-radioactive isotope.

8. A method of generating radioactive elements substantially as hereinbefore described with reference to the accompanying drawings.

9. Apparatus when used for carrying out the methods claimed in any of the Claims 1 to 8, substantially as described with reference to the accompanying drawings.

Dated the 9th day of April, 1935.

CLAREMONT HAYES & CO.,
Vernon House, Sicilian Avenue,
Bloomsbury Square, W.C.1,
Applicant's Solicitors.

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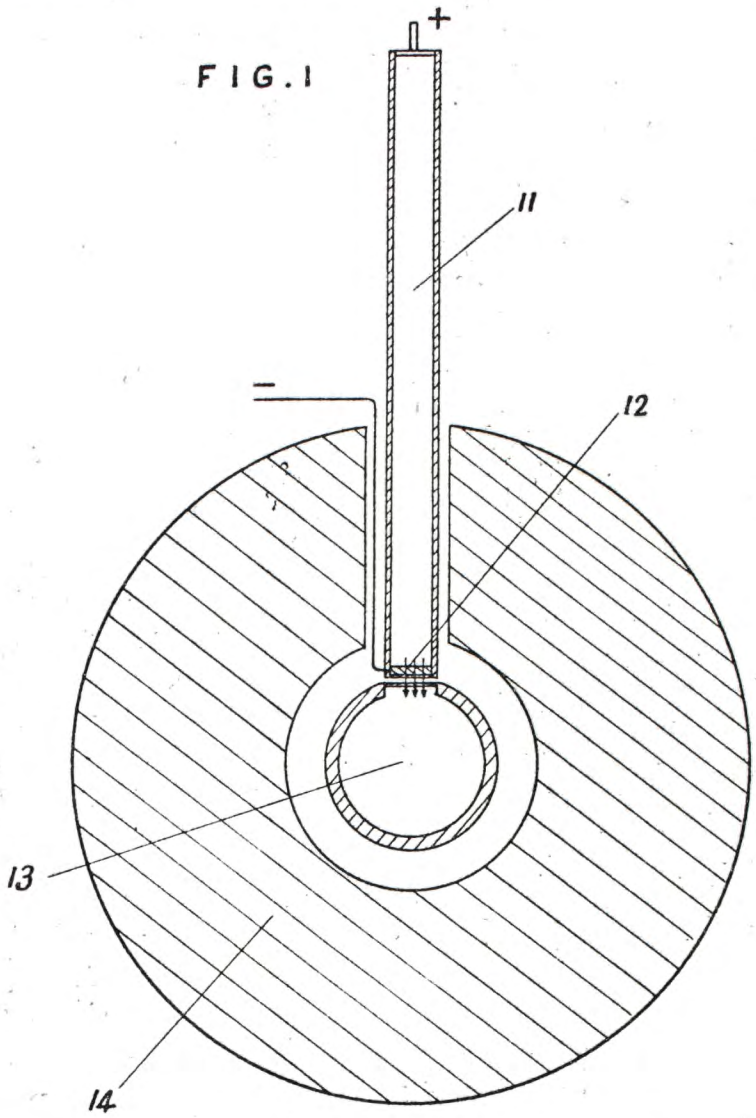
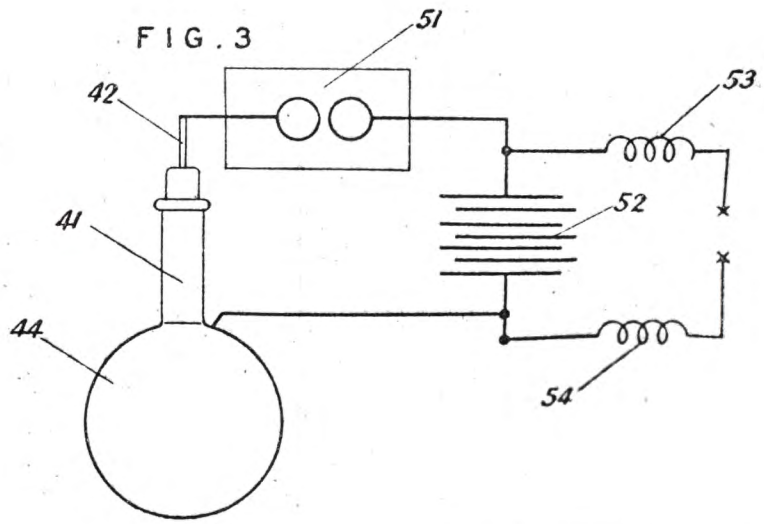
SHEET 1

FIG. 1



SHEET 3

FIG. 3



[This Drawing is a reproduction of the Original on a reduced scale.]

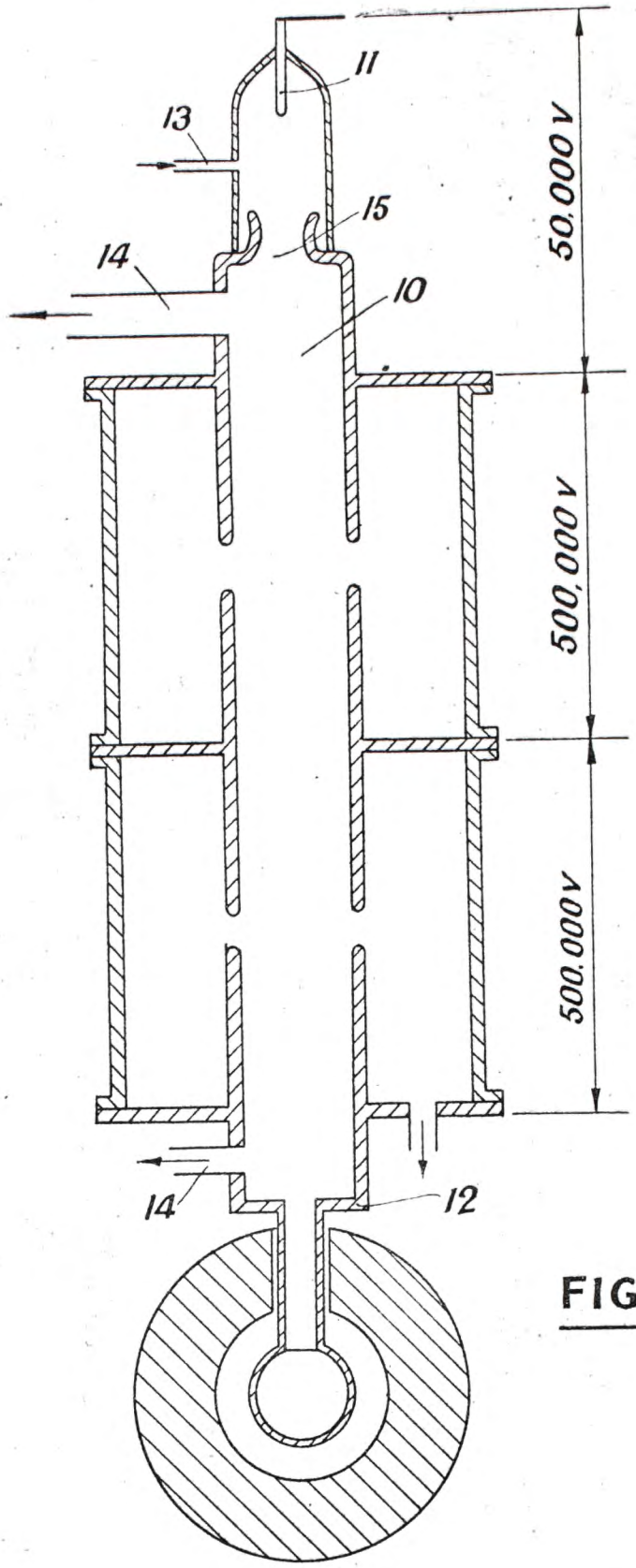


FIG. 2

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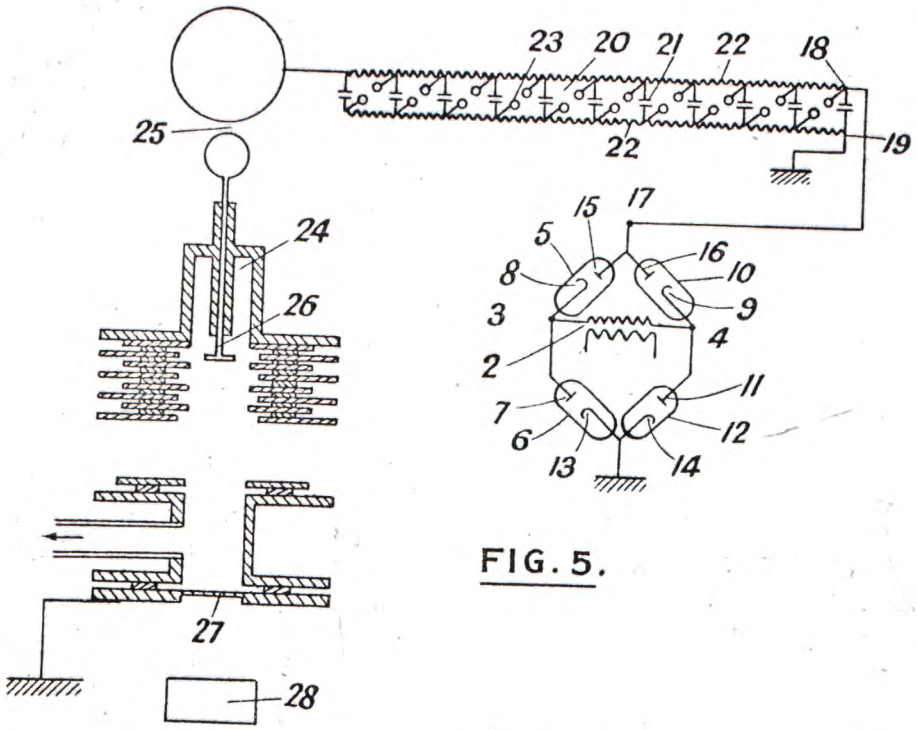

FIG. 5.

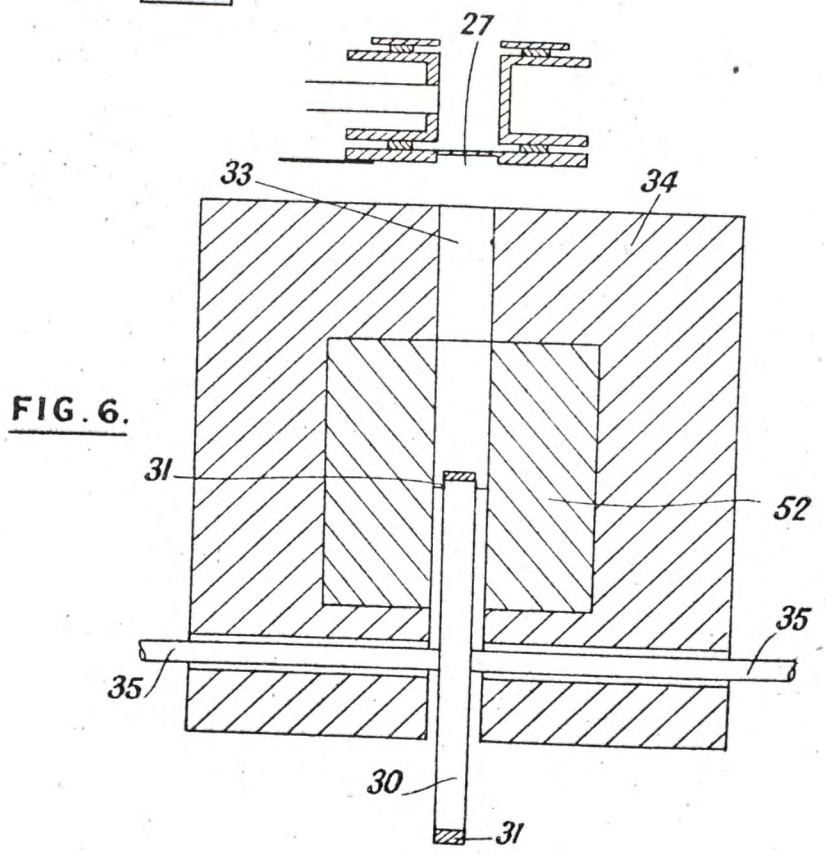

FIG. 6.

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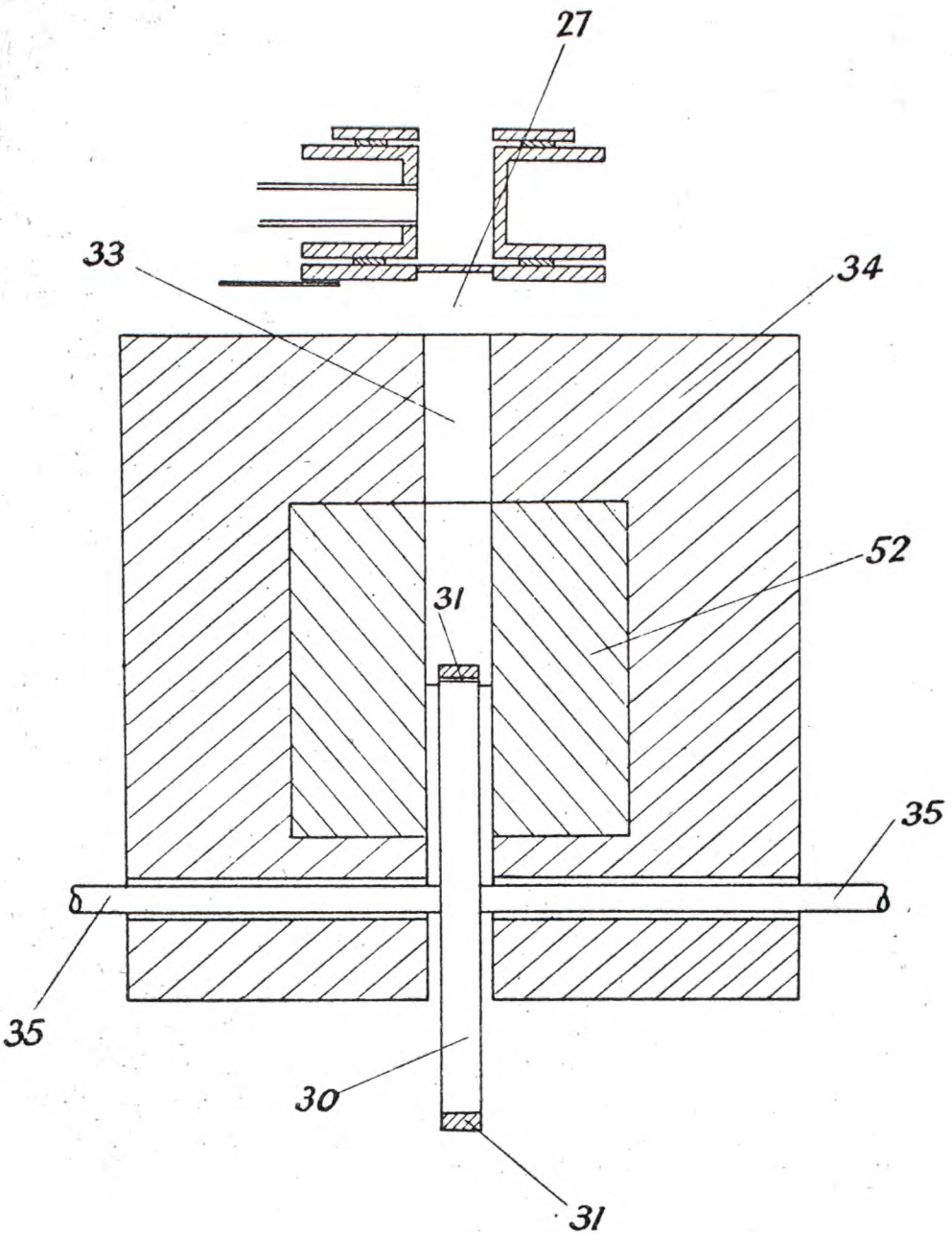

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[This Drawing is a reproduction of the Original on a reduced scale.]

FIG. 1.

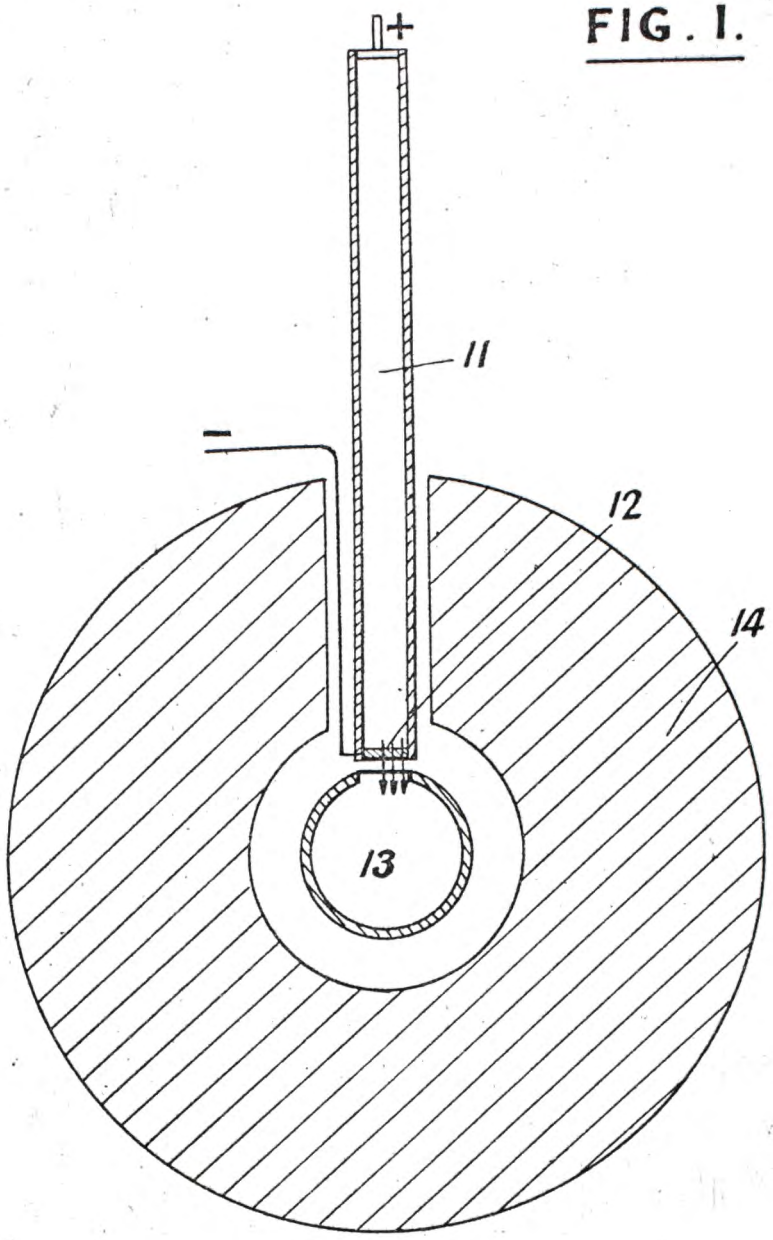

FIG. 2

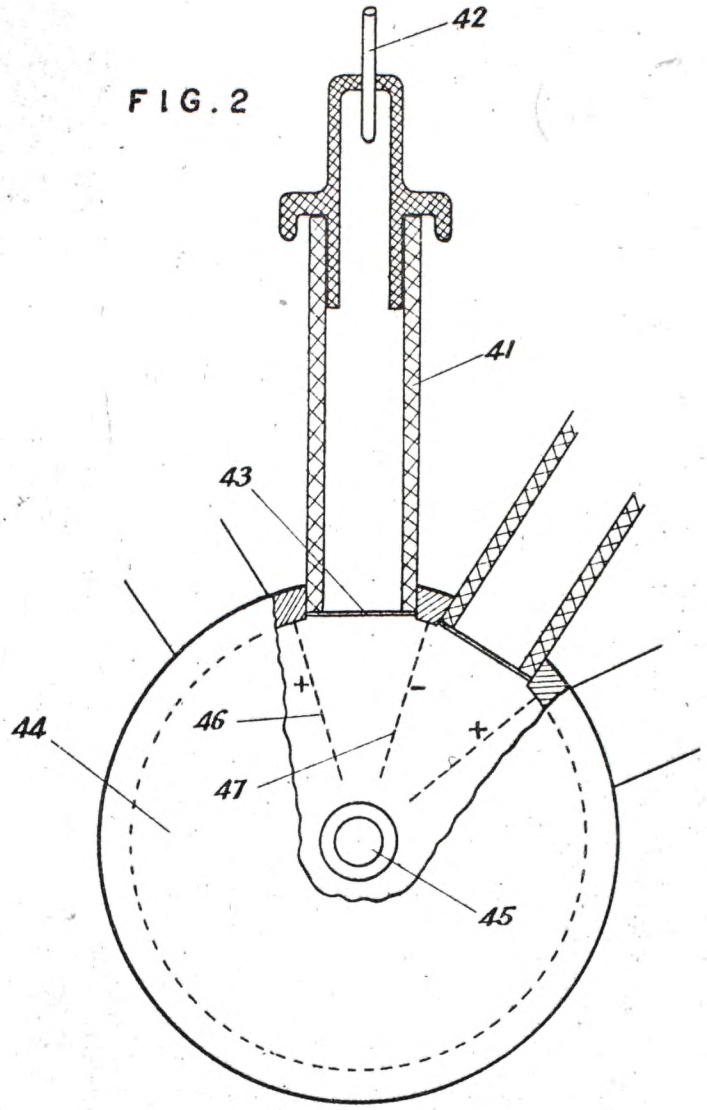

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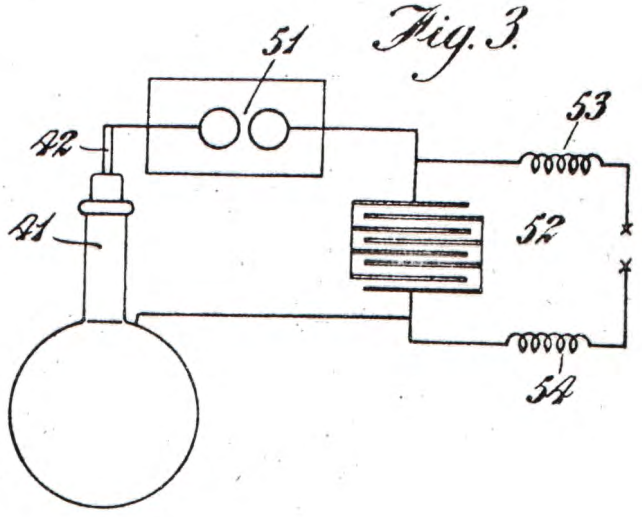
Fig. 3.



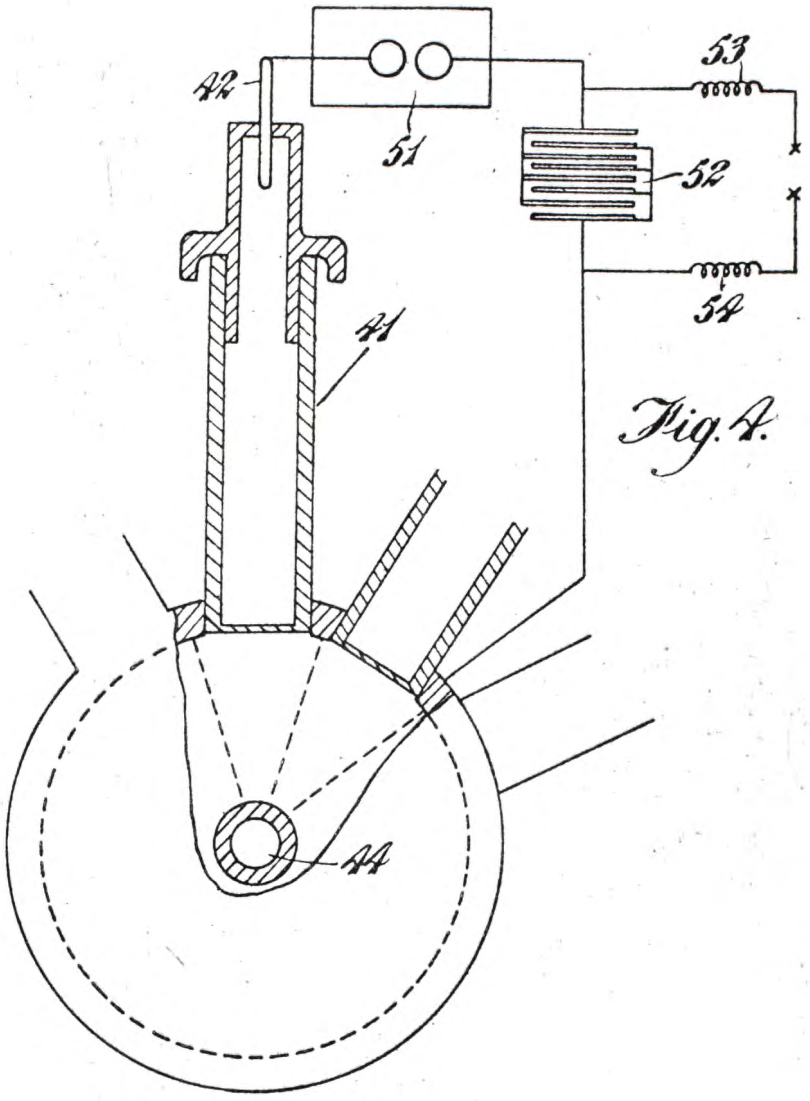


Fig. 4.

Brit. Pat 440,023

Dec 12. 1935

Jerry Mauer