Form P. Ack. 4.

THE PATENT OFFICE,

No. **27507**

25, Southampton Buildings,
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Date 25 SEP. 1934

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

which have been numbered and dated as above.

M. F. LINDLEY,

Comptroller-General.

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The number and date of this Application must be quoted on the Complete Specification and Drawings (if any), as well as in any correspondence relative thereto.

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Transmutation of matter by Pr. Avelas.
[illegible]

Transmutation of Matter by Sygma Particles.

The invention concerns the generation of power and the storage of power by the generation of radioactive bodies and the generation of radioactive bodies in general by a radiation called from now on sygma radiation. Such a sygma radiation can be generated by bombarding certain elements with neutrons, especially such elements which swallow the neutrons like iodine, arsenic, bromine etc. which transmute into their own radioactive isotopes, but also other elements which do not show an appreciable induced activity. One can determine by studying the non-elastic scattering of neutrons which elements swallow neutrons, but the best way to determine directly which elements show a strong sygma radiation when bombarded by neutrons is the following. We bombard the element under investigation by neutrons and expose to the sygma radiation which this element possibly emits one element after the other, and observe for each element after a sufficiently long irradiation if it shows an induced radioactivity which is not due to the direct action of the neutron radiation. The sygma radiation reveals its presence by inducing radioactivity in certain elements. In this way we can investigate for each element if it emits a sygma radiation or not when bombarded by neutrons.

Another characteristic of the sygma radiation which can lead to its detection is its ability to liberate neutrons from certain elements. By exposing to an element the sygma radiation of which we wish to determine one element after the other and by observing whether any of these elements emit neutrons (if the element under investigation is bombarded by neutrons) we can investigate the sygma radiation for each element. In this way we also find pairs of elements which have the following property. The sygma radiation of the one element liberates neutrons in the other, and the neutrons liberated in this way again excite sygma radiation in the first element and so on, so that we get a chain reaction.

Such chain reactions permit to get an increased output of radioactive bodies (generated by the neutrons or the sygma particles) and also a large output of energy. The links of the chains are formed by at least two different kinds of 'particles' which may appear and disappear alternatingly in the chain reaction which we wish to describe. One of the particles is a neutron, the other particle is a sygma quantum. We do not wish to differentiate between the possible components of sygma radiation and call a sygma quantum a unit of radiation which is emitted by an element when bombarded by neutrons. Such a sygma quantum may be some sort of known or unknown particle or a gamma quantum and when a neutron is absorbed by the atom of an element one, two or more sygma particles may be emitted. We have to differentiate between chains that can be maintained in pure elements and chains which must be maintained in mixtures of elements. We must further differentiate between non-divergent and divergent chains.

1. <u>Chains in pure elements:</u>

a) Non-divergent chains. If we have an element which emits only one sygma particle when swallowing one neutron, and if the same sygma particle is able to knock out only one neutron from the same element, we have to deal with a non-divergent chain. In the first process the element transmutes into an isotope, the mass number of which exceeds by one the mass number of the original element. In the second process it transmutes into an isotope the mass number of which is one lower than the mass number of the original element. Energy is liberated in the process if the sum of the isotopic masses of the two isotopes below and above the original element is smaller than twice the isotopic mass of the original element. If we consider a process in which the atom swallows a neutron and emits one sygma 'particle' and the inverse process into which another atom (of the same atomic number and a mass number which exceeds by one the mass number of the first atom) absorbes the sygma particle and ejects a neutron, we are able to foretell with the help of the laws of the thermo-dynamic equilibrium the ratio of the probabilities (of the cross-sections) for the two processes. The cross section for the swallowing of a neutron is large for many elements and the mass of the sygma particles is small. It follows, therefore that the cross section for the disintegration by the sygma particle is large. Accordingly the mean free path of the sygma particles is very short in such cases.

b) If in a certain fraction of cases two sygma particles are emitted we get a divergent chain along which the number of sygma particles and neutrons increases.

2. Chains in Mixtures.

If we mix two elements or use a compound of two elements or arrange them so as to expose them to each other's radiation we can maintain a chain inwhich neutrons and sygma particles alternate, leading to an increase in the mass number of one element A and to a decrease in the mass number of the other element B. Again energy is liberated if the sum of the isotopic masses of the two new elements is smaller than the sum of the two isotopic masses of the two older ones. In all these cases, and also in the case discussed under No. 1 the newly formed elements need not necessarily be stable but can immediately disintegrate, (for instance into their own parts in such a way that the sum of the atomic numbers of the parts and the sum of the mass numbers of the parts are equal to the atomic number and the mass number of the disintegrating element).

Again as pointed out under 1a, if only one sygma particle is emitted when an atom interacts with a neutron, especially if an atom swallows a neutron, the laws of thermo-dynamic equilibrium give a simple formula for the ratio of the probabilities (of the cross sections) of the process and of its inverse, and thereby determine the order of magnitude of the mean free path of the sygma quant in matter. It must be born in mind that we use the words "sygma particle" here generally for any particle or quantum which is emitted when neutrons interact with certain elements. It is, therefore, possible that the sygma particles which are emitted in a process in which a neutron is swallowed by an atom are of a different nature in the process in which only one particle is emitted, and in a process in which two particles are emitted by the same atom when a neutron is swallowed. It is possible that the two particles emitted in such a process are gamma quanta without necessarily following that the one particle emitted in such a process is also a gamma quantum, and there are indications that it is not.

In order to differentiate between the two kinds of ~~gamma~~ sygma radiation we shall call them 'singulet' and 'doublet' radiation. The existance of a sygma radiation, especially of a singulet radiation, can be revealed through its ability to cause a transmutation in matter, leading to the generation of radioactive bodies. If we generate sygma particles, especially singulet sygma radiation in an element, and allow it to fall on another element, we might in certain cases observe a radioactivity which will indicate the presence of sygma radiation.

If we generate the sygma radiation, especially the singulet radiation, by bombarding an element with neutrons and expose to the radiation emitted by the bombarded element a second element (for instance by mixing the two elements) it is possible that the second is transmuted into a radioactive body, and that we observe a radioactivity which cannot be generated by bombarding either of the elements with neutrons. Similarly it is possible that a sygma radiation generated in an element will transmute the same element into a radioactive body. In such a case if we generate the sygma radiation by bombarding the element by neutrons, we get the generation of the radioactive body only if we bombard a thick layer of the element by neutrons and not if we bombard a very thin layer of the element by neutrons.

Leave out.

Evidently elements which have several isotopes must be considered as mixtures of several elements from our point of view, and they come under point 2 rather than under point 1.

As mentioned before, the mean free path of a singulet sygma quantum which is emitted if a neutron is swallowed by an atom is determined for the inverse process by the laws of thermo-dynamic equilibrium. If, for instance, we consider the special case of the capture of a neutron by a proton with the emission of a singulet sygma quant, ~~in~~ and the inverse process in which a diplogen atom is disintegrated by a sygma quantum, the following equation holds for the cross-sections of the two processes:

$$\frac{\sigma_1}{\sigma_2} = 2\left(\frac{P'}{P}\right)^2$$

In this equation σ_1 is the cross-section for the capture of the neutron, and σ_2 the cross-section for the disintegration of diplogen. P is the momentum of the neutron, P' is the momentum of the sygma quant. As we can neglect the mass of the sygma quant. we get

$$\frac{\sigma_1}{\sigma_2} = A.B; \quad A = \frac{E}{E - \text{Binding Energy of Dipl.}}$$

$$B = \frac{E\,(\text{in M.E.V})}{1004}$$

In these equations E stands for the energy of the sygma particle

If we assume that the sygma quant carries an energy of

2.6 M.E.V. and that diplogen has a binding energy of 1 M.E.V. we get roughly for the ratio of the two cross-sections 100.

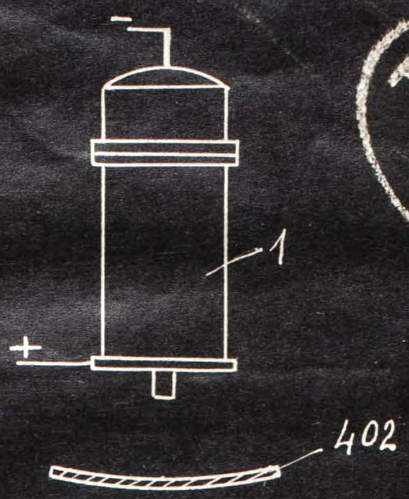
We can generalise that in many cases sygma quant will have a cross-section of about 100 times larger than neutrons so that the mean free path of the sygma quant (defined by their interaction with matter, leading to a transmutation process) will be smaller than the mean free path for a neutron (leading to transmutation). In many cases the mean free path of the sygma quanta will be of the order of a couple of cms in the solid and liquid state under ordinary conditions. This corresponds to the fact that the cross-sections of neutrons for being captured is very large ~~inducing radioactivity is of the order of 10^{24} to 10^{26} square cms. and very often 10^{25} square cm.~~

If we wish to generate radio-active bodies we can therefore make use of the sygma radiation in the following way. We bombard a ~~x/element~~ body built of a suitable element by neutrons and generate thereby sygma radiation. We allow the radiation of the bombarded element to fall on a body of another element which transmutes into a radioactive substance under the influence of this radiation. We choose the dimensions of the two bodies so that the linear dimensions of the first body should not be too small as compared to the mean free path of the neutrons (for the generation of sygma radiation) ~~generation~~ and the linear dimensions of the second body should not be too small as compared to the mean free path of the sygma radiation, (for the generation of radioactive atoms). Instead of using two bodies we can mix the two elements to form one body only. Pure elements which in many cases are mixtures of isotopes are special cases of such mixtures.

Figure 1 is an example for the generation of radioactive bodies. 27 is the window of a high voltage electron tube operated at three million volts. The electrons ~~heat~~ hit the rotating anticathode 30 which is covered with lead 31 or tungsten. This anticathode is water-cooled, the water entering the rotating body through the axis 35. 32 is a block formed of a substance, for instance the mixture of several elements surrounded by a block 34 of beryllium. A space has been left in the inner block 32 for the rotating anticathode and for the path of the cathode rays 33 between the window 27 and the anticathode. The neutrons generated in the beryllium under the action of the X-rays generated in the lead anticathode generate sygma radiation in the inner body 32 which in its turn generates radioactive substances within the body 32. If the mean free path of both the neutrons and the sygma quanta in the body 32 is ~~small~~ large as compared to the linear dimensions of 32, the output is proportional to the square of these linear dimensions, and in such cases it is advisable to choose the linear dimensions of 32 as large as possible.

Figure 2 shows the utilisation of sygma quanta for producing power and for the storage of power by the generation of radioactive bodies on a large scale. 40 is a neutrons generator. The neutrons fall on a sphere 41 built of a substance in which the neutrons liberate ~~gamma~~ sygma quanta, which in their turn again liberate neutrons. The sphere 41 is water cooled and the heat developed in the process is utilised in the boiler shown in Figure 3. If the dimensions of the sphere 41 are properly chosen, the total number of the liberated sygma quanta and neutrons can be any desired multiple of the total number of neutrons generated by the neutron source 40. The neutrons emerging from the layer 41 generated in the layer 42 radioactive substances and the sygma quanta generated in the layer 41 generate in the layer 43 radioactive substances. As shown in Figure 3 the generated heat is utilised by means of the tubing system 111, 110, and 107-109 through which water is pumped by the pumps 120, 121 and 122. The hot water is pumped through the tubing systems 123, 124 and 125, thereby heating the boiler 126.

In Figure 4 we have another chain reaction system. The initial radiation of neutrons is here generated through the action of gamma rays on the beryllium sphere 407. Under the action of gamma rays which are generated in the anti-cathode 402 by the action of 3 million volt electrons generated by the cathode ray tube 1. The chain reaction takes place in the spherical layer 3, and sygma quanta and neutrons alternate in the chain. We can have both singulet sygma quanta alone alternating with neutrons, but the neutrons can also liberate two sygma quanta in one process so that neutrons disappear and two sygma quanta are created. In this and in other ways we can have divergent chains in which the number of neutrons and sygma quanta increases. The arrangement according to Figure 4 is very advantageous, for maintaining a chain reaction in a layer in which neutrons are liberated by the sygma quanta especially if the mean free path of the sygma quanta is much smaller than the mean free path of the X- rays (for the liberation of neutrons).



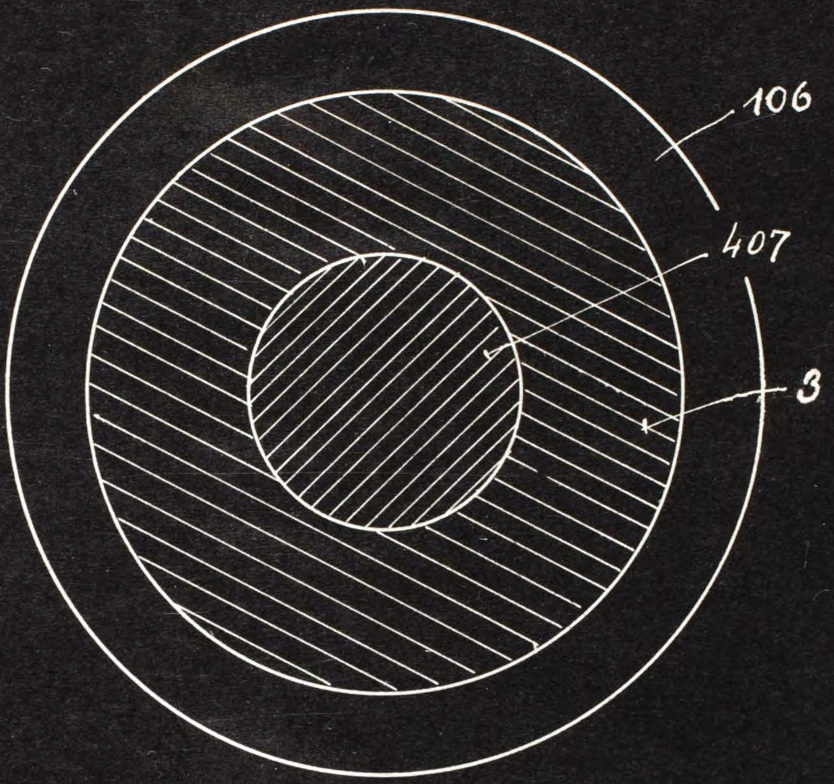


Fig. 4.

Dated this 4th day of July 1934

Leo Szilard

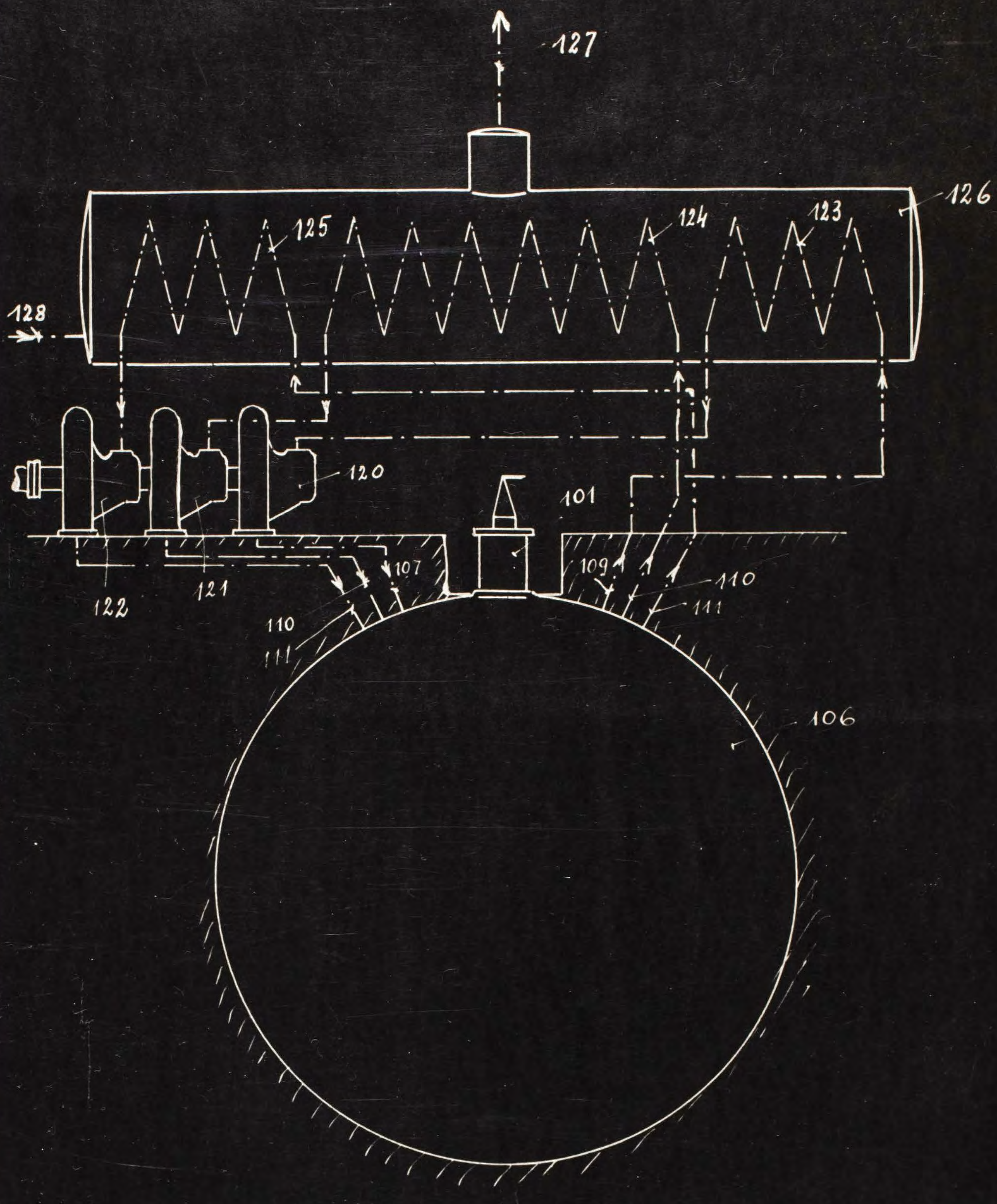

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Fig. 3

F. J. 58.

25. Sept
3

Fig 8 of 7840

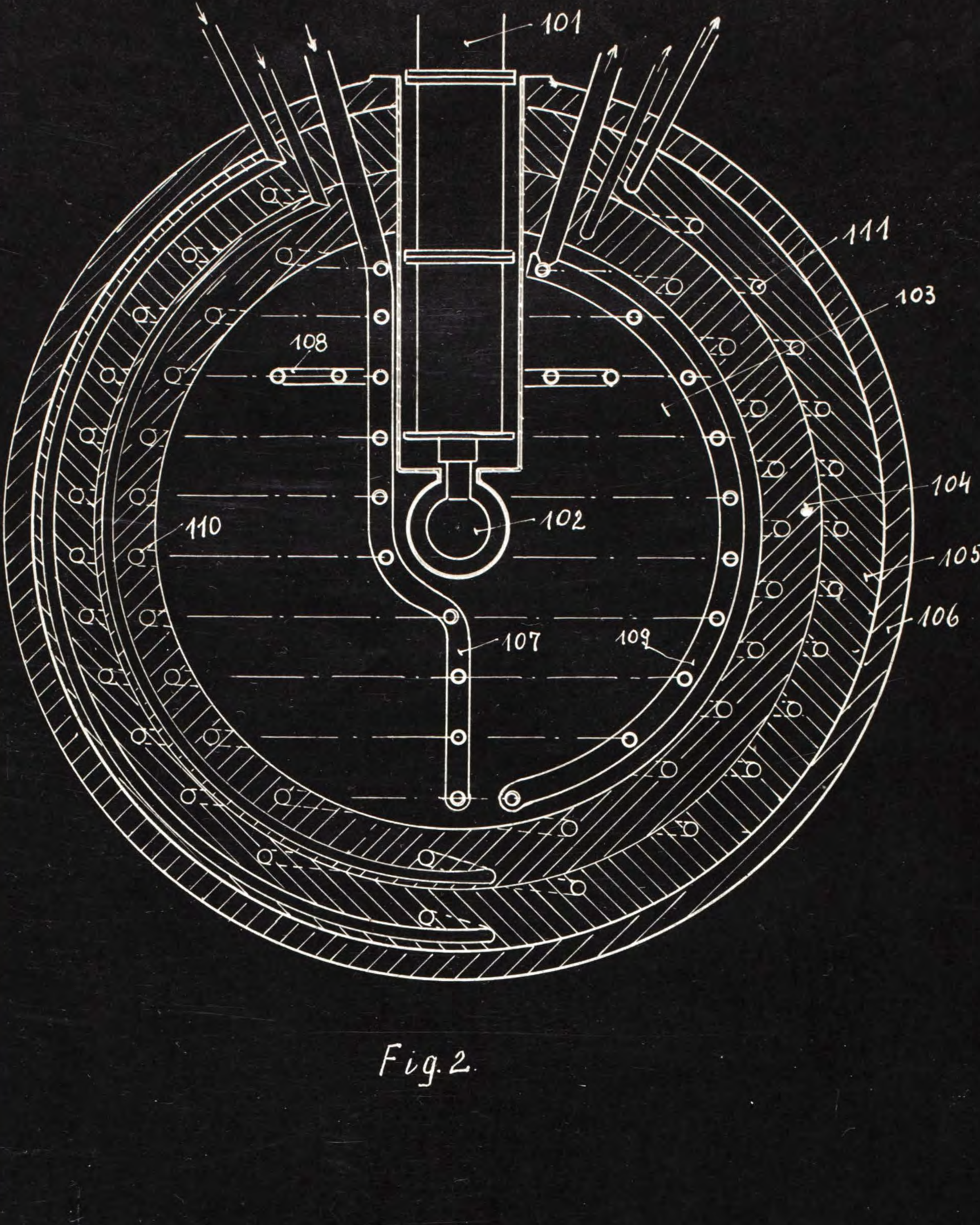

Fig. 2.

F. J. 58.

25. Sept
2

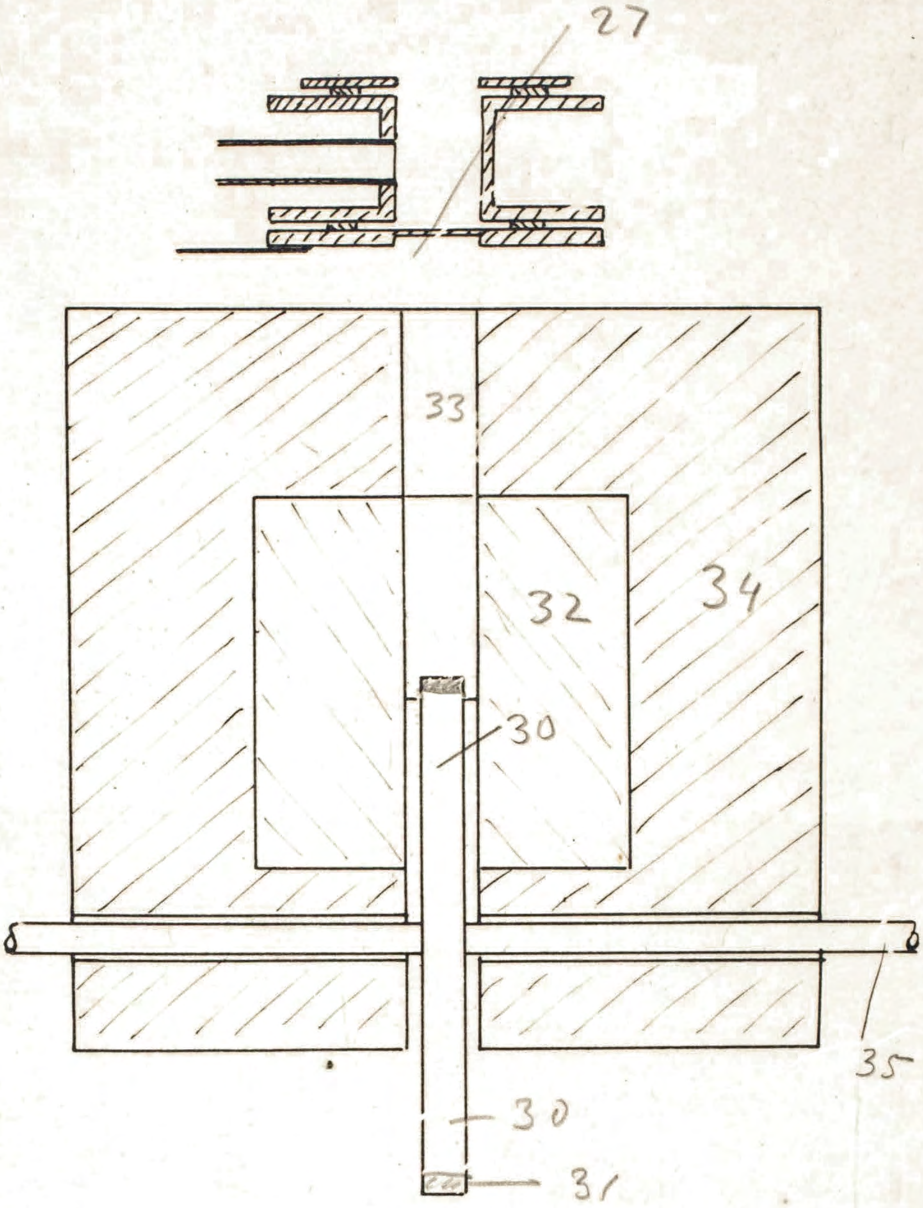

Fig. 21.

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(Fig. 6 of original #7840-) K.W.