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CYCLOTRON

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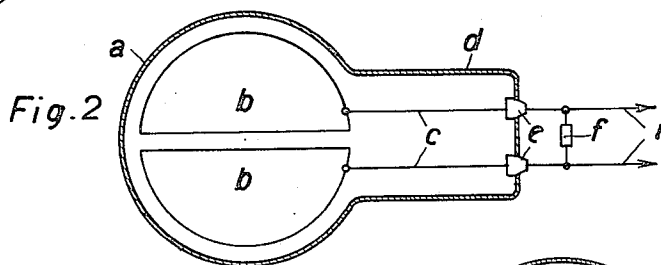
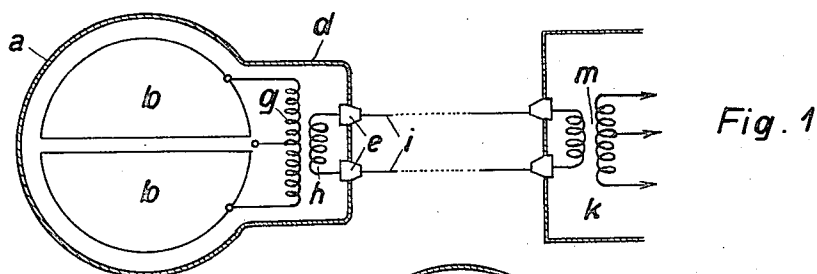


Fig. 3

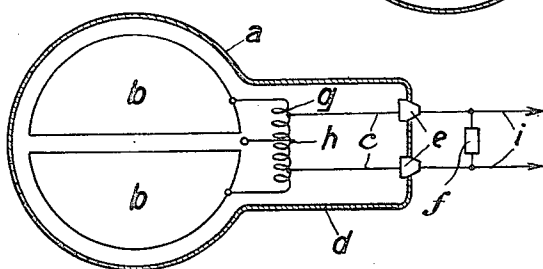


Fig. 4

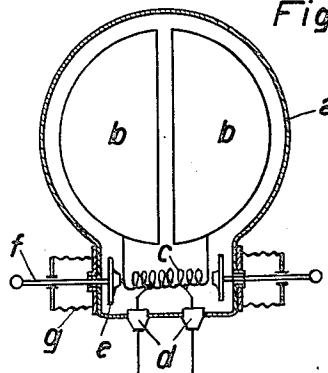


Fig. 5

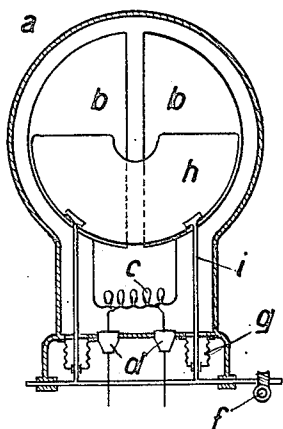


Fig. 6

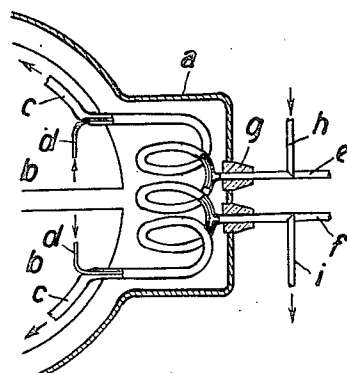
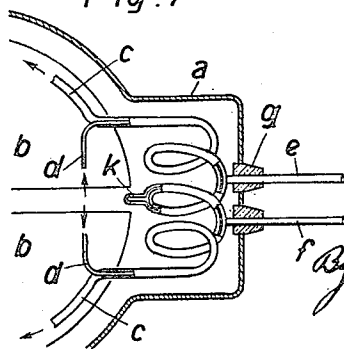


Fig. 7



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UNITED STATES PATENT OFFICE

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CYCLOTRON

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As is known the cyclotron is used to give electrically charged particles, for instance positive ions, a high velocity. The energy of the particles accelerated by means of the cyclotron is about equivalent to the energy which the particles would acquire when passing through a static potential of several million volts. The main advantage of the cyclotron when compared with an ordinary high voltage plant is that only voltages of about 40,000 to 80,000 volts, although in the form of a high frequency alternating voltage, are required in order to impart high velocities to the charge carriers. The cyclotron in its known form consists primarily of an accelerating chamber arranged between the poles of a powerful magnet. In this chamber there are usually only two accelerating electrodes which are formed by a circular box divided along a diameter into two halves. Each part of the box is connected to a pole of a high frequency generator and the device for creating the charge carriers is arranged in the centre of the space bounded by the box surfaces. Under the influence of the alternating electric field and the constant magnetic field the charge carriers travel along spiral paths with an outwardly increasing velocity. When the charge carriers have reached a certain maximum travel radius and acquired a corresponding energy then, by means of further devices, they are diverted out of the range of the magnetic field into the observation chamber, which in the usual way is also kept under a suitably high vacuum like the accelerating chamber.

The cyclotrons used up to the present still have various defects which prevent energies of more than 6 eMV (6 million electron volts) being produced. It has namely been found that the charge carriers can only make a certain number of revolutions without falling out of step, so that the maximum energy will be greater the higher the amplitude of the alternating voltages applied to the accelerating electrodes can be chosen. An increase in the peak value of the high frequency supply current is, however, accompanied by considerable difficulties as regards the construction of the bushing insulators, so that at present not much more than 70,000 volts high frequency voltage can be safely used. Even if it is assumed that the question of the insulation could be solved, due regard being given to the very high dielectric losses encountered in the insulation material when higher voltages are employed, the use of much higher voltages than has hitherto been the case is limited by the fact that due to unavoidable detrimental capacities the high frequency power

to be produced increases more than proportionally with the electrode voltage and it is doubtful if such installations would be economical.

The object of the present invention is therefore to construct a cyclotron which does not possess the disadvantages of the type hitherto used and which enables, with a considerably smaller high frequency power, such energies to be imparted to the charge carriers as have not been previously attained. A further advantage is that the chamber can be made more cheaply and reliably because the bushing insulators need only be designed for lower voltages. This is achieved by providing inside the accelerating chamber means for a voltage transformation of the high frequency oscillation supplied to the accelerating electrodes, in such a manner that the amplitude of the high frequency voltage at the place where the leading-in insulators are situated in the chamber is considerably smaller than the amplitude of the high frequency voltage prevailing between the accelerating electrodes.

In the drawing several constructional examples of the invention are illustrated diagrammatically. In Fig. 1 a voltage transformation by means of a transformer located inside the chamber is employed, whilst in Fig. 2 the transformation is achieved by the aid of a Lecher wire system, which is connected to the high frequency generator and the accelerating electrodes in such a way that a voltage intersection point occurs at the bushing insulators. In Fig. 3 both these means are combined in order to obtain a double transformation. Figs. 4 and 5 show two further embodiments of the invention whereby means are provided for adjusting the cyclotron circuit; whilst in Figs. 6 and 7 cooling arrangements for the electrodes are illustrated.

In the constructional examples shown in the drawing the wall of the accelerating chamber is shown in section, so that in the plan view the electrodes *b* inside the casing wall *a* are visible. On one side of the wall *a* there is a projection *d* at the end of which the bushing insulators *e* are situated. In Fig. 1 the electrodes *b* are connected directly with the secondary winding *g* of a high frequency transformer, the middle of the winding being preferably connected to the casing. The primary winding *h* of the transformer, which preferably consists of only one coil and is coupled as closely as possible with the secondary coil, is connected directly to the low ohmic conductors *i* which are supplied from the high frequency generator *k*. The tubes of the high frequency generator, normally operating as a reverse

rhythm end stage are connected to the high ohmic primary winding of the transformer m , the secondary coil of which is connected with the conductors i . It is obvious that with such a construction of the cyclotron extremely high voltages can be generated at the accelerating electrodes b without equally high voltages occurring at the bushing insulators. Furthermore the capacity of the insulators e and the conductor i is now only of minor importance so that inside the chamber for a resonance tuning of the secondary coil g with the effective capacity between the accelerating electrodes b , a weakly damped oscillating circuit will be obtained in which high resonance voltages can be excited. Although resonance tuning has already been employed for cyclotrons, the resonance voltages could not be forced up so high as in this case because the capacity of the old bushing insulators and the high ohmic conductors connected therewith was much too large to be able to obtain at a definite wave length an oscillating circuit inductance sufficiently free from losses. This fact is readily appreciated when it is considered that the effective capacity between the electrodes of the previously used construction only amounted to a fraction of the total circuit capacity whilst in this new construction the circuit capacity is primarily determined by the effective capacity between the electrodes. In accordance with the ratio of the reduced capacities the power of the high frequency generator can therefore also be correspondingly reduced or with the same power, for reasons already stated, considerably higher energies are obtained for the accelerated charge carriers. The construction used formerly also possesses further disadvantages because the coil used for the resonance tuning and arranged outside the chamber causes undesirable eddy currents in the surrounding metal parts, for instance in the iron masses of the electromagnets or in special metal casings, these resulting in a high loss factor. The coil outside the chamber produces on account of its large dimensions relative to the wave length, a strong radiation of high frequency power which must of course also be produced by the high frequency generator. If, however, the coil for resonance tuning is arranged inside the chamber, it is an easy matter to construct the metal surfaces of the casing wall so that the eddy current losses are considerably reduced and the radiation of high frequency energy is also completely suppressed by such screens.

With the inductive transformation shown in Fig. 1 it is possible to obtain a transformation ratio of more than 1 : 10, so that the bushing insulators need only be designed for at the most 10,000 volts. A somewhat higher ratio of transformation can be achieved with the arrangement shown in Fig. 2 where for the transformation a Lecher wire system c (parallel wire system) is arranged inside the chamber which is electrically so closed, for instance by means of an additional impedance device f , that as far as possible a voltage intersection point occurs at the bushing insulators e whilst at the accelerating electrodes b there is a voltage loop.

It has been found that a most suitable ratio of transformation for the inside of the chamber is about 1 : 30. This ratio of transformation results in a sufficiently low voltage at the insulators without the currents in the low ohmic conductors becoming too high. It is preferable that such a ratio of transformation should not be under-

taken in one stage but in a double transformation. For this purpose the arrangement shown in Fig. 3 is particularly favourable where first a transformation by means of a Lecher wire system occurs in such a manner that a voltage intersection point exists at the bushing insulators. The Lecher wire system, that is to say the part c of the system inside the chamber, is connected with the primary winding h of the high frequency transformer, the secondary winding g of which in the manner described for Fig. 1, is connected to the electrodes and tuned to resonance. As shown in Fig. 3 the high frequency transformer can also be constructed as an autotransformer in which the low ohmic primary coil h forms part of the high ohmic secondary coil g . As in Fig. 2, it is also possible with this alternative to provide the part i of the Lecher wire system outside the chamber with additional impedances f or to connect it to a Lecher wire system with a correspondingly different wave resistance, so that voltage loops with a high amplitude no longer occur.

With this construction of cyclotron, tuning elements can be provided in the high frequency conductors outside the accelerating chamber by means of which the alternating voltage on the accelerating electrodes must be accurately adjusted both as regards its amplitude and its frequency, in order that the required synchronous travel of the charge carriers to be accelerated can be controlled with the alternating voltage. It is therefore also of great importance that the cyclotron circuit be correctly tuned because the final energy of the charge carriers depends on this adjustment. The adjustment of the cyclotron circuit in the known arrangements is usually undertaken by means of additional variable coils, telescopic Lecher wires or capacities, which are arranged as near as possible to the bushing insulators of the chamber, so as to obtain a high resonance resistance for the cyclotron circuit. The usual arrangement of these switch elements is, however, accompanied by several disadvantages which make the use of the cyclotron somewhat complicated. The switch elements for regulating the impedance of the cyclotron circuit are, namely, under a high voltage and carry high frequency alternating voltages of several thousand volts, so that their operating handles must be particularly well insulated to enable them to be handled without danger. The insulation of the regulating elements themselves involves considerable difficulties if voltages of more than 100,000 volts are used in the chamber. With such high voltages it is absolutely necessary that these switch elements should have a certain size, so that no discharge to the atmosphere can occur. Particularly as regards the usual self-inductances arranged in series in the cyclotron circuit, such dimensions are obtained that these are comparable with the wave length of the high frequency radiation of high-frequency energy which must of course be covered by the tube generator. A further disadvantage is the large amount of space occupied by these regulating devices and these cannot be reduced for the reasons already stated.

These disadvantages are partly overcome in the cyclotron already described where inside the accelerating chamber means are provided for the voltage transformation of the high frequency oscillation applied to the accelerating electrodes in such a way that the amplitude of the high frequency voltage at the bushing insulators of the chamber is smaller than the amplitude of the

high frequency voltage prevailing between the accelerating electrodes. Despite this, the usual arrangement of adjustable switch elements outside the chamber gives poor results in this case, because often a comparatively slight electric coupling between the low ohmic leads arranged outside the chamber and the actual cyclotron circuit is preferred. This slight coupling also excludes a simultaneous tuning of the cyclotron circuit and an adjustment of the impedance to the connecting leads. Even when regulating on the low ohmic side extensive switch elements are still necessary, because although the insulation question is no longer so important, considerably larger currents are carried by the switch elements. Furthermore, with the most usual arrangement of telescopic Lecher wires the space requirements are about the same as with regulation on the high voltage side.

In accordance with the invention these disadvantages of the known devices can be avoided and a further considerable improvement in the cyclotron achieved by arranging at least one variable tuning element in the interior of the accelerating chamber for electrically balancing the resultant impedance of the high frequency cyclotron circuit, this element being actuated from outside through a bushing. Fig. 4 of the drawing shows an arrangement where an inductance inside the accelerating chamber can be varied and Fig. 5 illustrates an arrangement where an adjustable capacity is used for tuning the cyclotron circuit.

In Fig. 4 the accelerating chamber *a* is shown in plan, the cover plate being removed. The semi-circular accelerating electrodes *b* are connected as an auto-transformer which serves to transform the high frequency voltage so that only comparatively low voltages occur at the bushing insulators *d*. The natural frequency of the cyclotron circuit is thus mainly determined by the mutual capacity of both electrodes *b* and the effective self-induction of the coil *c*. In order to vary the voltage on the electrodes *b* or to adjust the impedance of the circuit during the operation of the cyclotron, two metal pieces *e* are provided which by means of the regulating devices can be moved into or out of the coil field so that their self-inductance can be varied within certain limits. The regulating devices *f* are arranged to pass through vacuum tight glands *g* so that the self-inductance *c* can also be adjusted when the cyclotron is in operation. As shown in the drawing, the glands are provided with a flexible membrane, preferably in the form of a compressible corrugated tube, the outer edge of which is fastened to the casing in a vacuum-tight manner, whilst the regulating element passes through the centre of the membrane, for instance by means of an air-tight flange. In a corresponding manner it is possible by making use of the leakage of a high frequency transformer to alter the effective transformation ratio for the operating frequency by influencing the leakage field.

In the arrangement shown in Fig. 5 not the self-inductance but the effective capacity of the cyclotron circuit is varied, in order to obtain the required adjustment. For this purpose a metal plate *h* is provided which through the supports *i* can be rotated by the spindle *j* arranged outside the chamber, so that the distance between *h* and the electrodes *b* can be varied. The glands *g* also preferably consist of sections of corrugated tube.

Instead of a single condenser plate, two adjustable plates can be used, each of which is associated with an accelerating electrode. This

enables the capacity of each accelerating electrode with respect to the casing to be adjusted independently of the other electrode, so that it is possible to fix the voltage distribution of both electrodes with respect to the casing as desired. Such a symmetrical arrangement is of course also possible with the device shown in Fig. 4. With such arrangements for regulating the voltage distribution it is preferable to connect the middle point of the coil *c* to the casing.

The special advantage of locating the tuning element inside the accelerating chamber is that less space is required and the regulating device can be arranged within easy reach of the observer. From the electrical point of view the tuning elements described are also superior to those connected outside the chamber, because the insulation of external switch elements depends on the dielectric losses or the break down voltage of the air, whilst with internal switch elements the minimum distances are only limited by the auto-electronic effect which only becomes noticeable with field strengths of several hundred thousand volts per centimetre. It is also very favourable that high frequency radiation is prevented and that the construction is very safe in operation due to the possibility of a direct galvanic connection of the tuning elements with the casing.

With a cyclotron it is also necessary to cool the accelerating electrodes inside the chamber by providing additional cooling means for this purpose. The construction of such cooling means is accompanied by considerable difficulties because the accelerating electrodes in rhythm with a high frequency oscillation carry very high voltages of about 70,000 volts compared with the casing. Up to the present it has therefore been usual to arrange the cooling medium pipes for each accelerating electrode inside the high frequency leads themselves. Each of the high frequency leads from the chamber consists of two concentric pipes, one of which serves for the ingoing and the other for the outgoing flow of cooling water. Outside the chamber the cooling medium circuit is branched off from the high frequency conductors, this being accomplished by means of two comparatively involved flexible spiral tube pieces connected to each conductor and acting as choke coils for the high frequency. For cooling both electrodes four such choke coils are therefore necessary; these can, however, be arranged in pairs either interwound or in the form of concentric tubes or pipes. On account of the large adjacent high frequency voltages these choke coils occupy a large amount of space if it is desired to avoid a powerful high frequency shunt which absorbs valuable high frequency power. Apart from their complicated and expensive construction these large choke coils also possess the disadvantage that they have a damping effect on the cyclotron circuit, this being caused by radiation or the undesirable increase in the capacity of the high frequency supply circuit.

These disadvantages can be avoided in a cyclotron in which inside the accelerating chamber means are provided for a voltage transformation of the high frequency oscillation supplied to the accelerating electrodes in such a way that the amplitude of the high frequency voltage at the bushing insulators of the chamber is considerably smaller than the amplitude of the high frequency voltage prevailing between the accelerating electrodes. This is achieved by using the high frequency leads to the accelerating elec-

trodes at least partly also as a cooling medium circuit for cooling the accelerating electrodes and by branching off the cooling medium circuit from the high frequency leads at a point where the high frequency voltage is smaller than the high frequency voltage on the accelerating electrodes.

Fig. 6 shows a constructional example where the branching off of the cooling circuit from the high frequency leads occurs outside the accelerating chamber, whilst in Fig. 7 the junction is inside the chamber.

In Fig. 6, *a* is the casing of the accelerating chamber in which the semi-circular accelerating electrodes *b* to be cooled, are arranged. The course of the cooling medium inside the electrodes themselves is not shown in the drawing and can be arranged in a known manner. The cooling medium passes into and out of each of the electrodes *b* through the concentrically arranged pipes *c*, *d*; the cooling water entering through the pipe *c* and leaving through the pipe *d*. The pipe *c* together with the internal pipe *d* is wound to form a self-inductance which is located inside the accelerating chamber. Inside the chamber there are also the high frequency supply conductors *e*, *f* connected to branch points on the pipe coil, so that this acts as a step-up transformer, with the result that there are only comparatively low voltages on the supply conductors *e*, *f*, that is to say at the place where the bushing insulators are situated. In practice a transformation ratio of 1:25 is selected for the high frequency transformer so that the supply and discharge of the cooling medium and the branching off of the cooling medium circuit can easily be undertaken outside the chamber on the low ohmic conductors *e*, *f*. In view of the low voltages and the small impedance of the conductors very simple pipe coils can be used, which need only consist of a small number of turns and are joined to the pipe connections *h*, *i*. The constructional example shown in Fig. 6 enables, in a very simple manner, the cooling medium to be supplied through one of the high frequency conductors *e*, whilst the other conductor *f* serves solely for the discharge of the cooling medium. Compared with the usual cooling arrangements only two simple pipe coils having relatively small dimensions and acting as choke coils, are required. The distribution of the cooling medium for the two electrodes occurs in the manner illustrated in the pipe system of the high frequency transformer. The ends of the pipe coil acting as choke coils and furthest removed from the pipe connections *h*, *i* are preferably arranged to lead together to the re-cooling plant and circulating pump and it is expedient to intertwine them so that they are connected together electrically or short-circuited for the operating frequency of the alternating currents.

These high frequency choke coils in the cooling medium circuit can be omitted if, as shown in Fig. 7, the centre point *k* of the secondary winding of the high frequency transformer is connected to the casing of the chamber and the incoming and outgoing flow of cooling medium occurs over this centre point. The main advantage of this arrangement is that the high frequency conductors *e*, *f* can be coupled over a galvanically separated primary coil with the secondary coil and that the high frequency supply circuit for the purpose of further voltage transformation can possess inside the chamber sections of Lecher wires, so that greater freedom as regards electrical adjustment is obtained.

Although several embodiments of the present

invention have been illustrated and described, it will be apparent to those skilled in the art that various changes and modifications may be made without departing from the spirit of the invention or the scope of the appended claims.

I claim:

1. A cyclotron comprising a casing providing a chamber, opposed accelerating electrodes in said chamber and electric circuit elements passing into said chamber through insulating bushings and connecting said electrodes with a source of high frequency oscillating current, said circuit elements including a high frequency transformer inside said chamber, said transformer comprising an auto-transformer in which the primary coil is a part of the secondary coil, the primary of said transformer being directly connected to a Lecher wire system leading through the insulating bushings into said chamber, said system being closed by a voltage junction point in the vicinity of the insulating bushings, and the secondary of said transformer being directly connected to said accelerating electrodes.

2. A cyclotron comprising a casing providing a chamber, opposed accelerating electrodes in said chamber and electric circuit elements passing into said chamber through insulating bushings and connecting said electrodes with a source of high frequency oscillating current, said circuit elements including a high frequency transformer inside said chamber, the primary of said transformer being directly connected to conductor elements passing into said chamber, the ends of the secondary of said transformer being directly connected to said accelerating electrodes, the electrical midpoint of the secondary being connected to the casing of said chamber, and the secondary coil being in resonance with the resultant capacity between the accelerating electrodes at the operating frequency.

3. A cyclotron comprising a casing providing a chamber, opposed accelerating electrodes in said chamber and electric circuit elements passing into said chamber through insulating bushings and connecting said electrodes with a source of high frequency oscillating current, said circuit elements including a high frequency transformer inside said chamber, the primary of said transformer being directly connected to conductor elements passing into said chamber, the secondary of said transformer being directly connected to said accelerating electrodes, at least one tuning element positioned inside said chamber, and means passing through the casing of said chamber for actuating said tuning element from outside the chamber.

4. A cyclotron comprising a casing providing a chamber, opposed accelerating electrodes in said chamber and electric circuit elements passing into said chamber through insulating bushings and connecting said electrodes with a source of high frequency oscillating current, said circuit elements including a high frequency transformer inside said chamber, the primary of said transformer being directly connected to conductor elements passing into said chamber, the secondary of said transformer being directly connected to said accelerating electrodes, at least one variable capacity positioned inside said chamber, and means passing through the casing of said chamber for actuating said variable capacity from outside the chamber.

5. A cyclotron comprising a casing providing a chamber, opposed accelerating electrodes in said chamber and electric circuit elements pass-

ing into said chamber through insulating bushings and connecting said electrodes with a source of high frequency oscillating current, said circuit elements including a high frequency transformer inside said chamber, the primary of said transformer being directly connected to conductor elements passing into said chamber, the secondary of said transformer being directly connected to said accelerating electrodes, at least one tuning element positioned inside said chamber, and means passing through a flexible member attached to the casing of said chamber for actuating said tuning element from outside the chamber.

6. A cyclotron comprising a casing providing a chamber, opposed accelerating electrodes in said chamber and electric circuit elements passing into said chamber through insulating bushings and connecting said electrodes with a source of high frequency oscillating current, said circuit elements including a high frequency transformer inside said chamber, the primary of said transformer being directly connected to conductor elements passing into said chamber, the secondary of said transformer being directly connected to said accelerating electrodes, at least one metal plate in said chamber adjacent an accelerating electrode, and means passing through the casing of said chamber for altering the position of said plate with respect to the electrode from outside the chamber.

7. A cyclotron comprising a casing providing a chamber, opposed accelerating electrodes in said chamber and electric circuit elements passing into said chamber through insulating bushings and connecting said electrodes with a source of high frequency oscillating current, said circuit elements including a high frequency transformer inside said chamber, the primary of said transformer being directly connected to conductor elements passing into said chamber, the secondary of said transformer being directly connected to said accelerating electrodes, at least a portion of said circuit elements being hollow and serving to conduct a cooling medium to and from the accelerating electrodes, the junction of the cooling medium supply and the hollow circuit elements being positioned at a point where the voltage on the circuit elements is substantially lower than the voltage on the electrodes.

8. A cyclotron comprising a casing providing a chamber, opposed accelerating electrodes in said chamber and electric circuit elements passing into said chamber through insulating bushings and connecting said electrodes with a source

of high frequency oscillating current, said circuit elements including a high frequency transformer inside said chamber, the primary of said transformer being directly connected to conductor elements passing into said chamber, the secondary of said transformer being directly connected to said accelerating electrodes, at least a portion of said circuit elements being hollow and serving to conduct a cooling medium to and from the accelerating electrodes, the junction of the cooling medium supply and the hollow circuit elements being positioned at a point outside the chamber where the voltage on the circuit elements is substantially lower than the voltage on the electrodes.

9. A cyclotron comprising a casing providing a chamber, opposed accelerating electrodes in said chamber and electric circuit elements passing into said chamber through insulating bushings and connecting said electrodes with a source of high frequency oscillating current, said circuit elements including a high frequency transformer inside said chamber, the primary of said transformer being directly connected to conductor elements passing into said chamber, the secondary of said transformer being directly connected to said accelerating electrodes, at least a portion of said circuit elements being hollow and serving to conduct a cooling medium to and from the accelerating electrodes, the junction of the cooling medium supply and the hollow circuit elements being positioned in the immediate vicinity of the insulating bushings at a point where the voltage on the circuit elements is substantially lower than the voltage on the electrodes.

10. A cyclotron comprising a casing providing a chamber, opposed accelerating electrodes in said chamber and electric circuit elements passing into said chamber through insulating bushings and connecting said electrodes with a source of high frequency oscillating current, said circuit elements including a high frequency transformer inside said chamber, said transformer comprising an auto-transformer in which the primary coil is a part of the secondary coil, the primary of said transformer being directly connected to conductor elements passing into said chamber, and the secondary of said transformer being directly connected to said accelerating electrodes, said transformer coil being hollow and serving to conduct cooling medium to and from said accelerating electrodes, the cooling medium being supplied to and removed from said coil through hollow conductor members.

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