

March 6, 1956

W. M. BROBECK

2,737,589

ION SOURCE FOR A CALUTRON

Filed Feb. 19, 1945

6 Sheets-Sheet 1

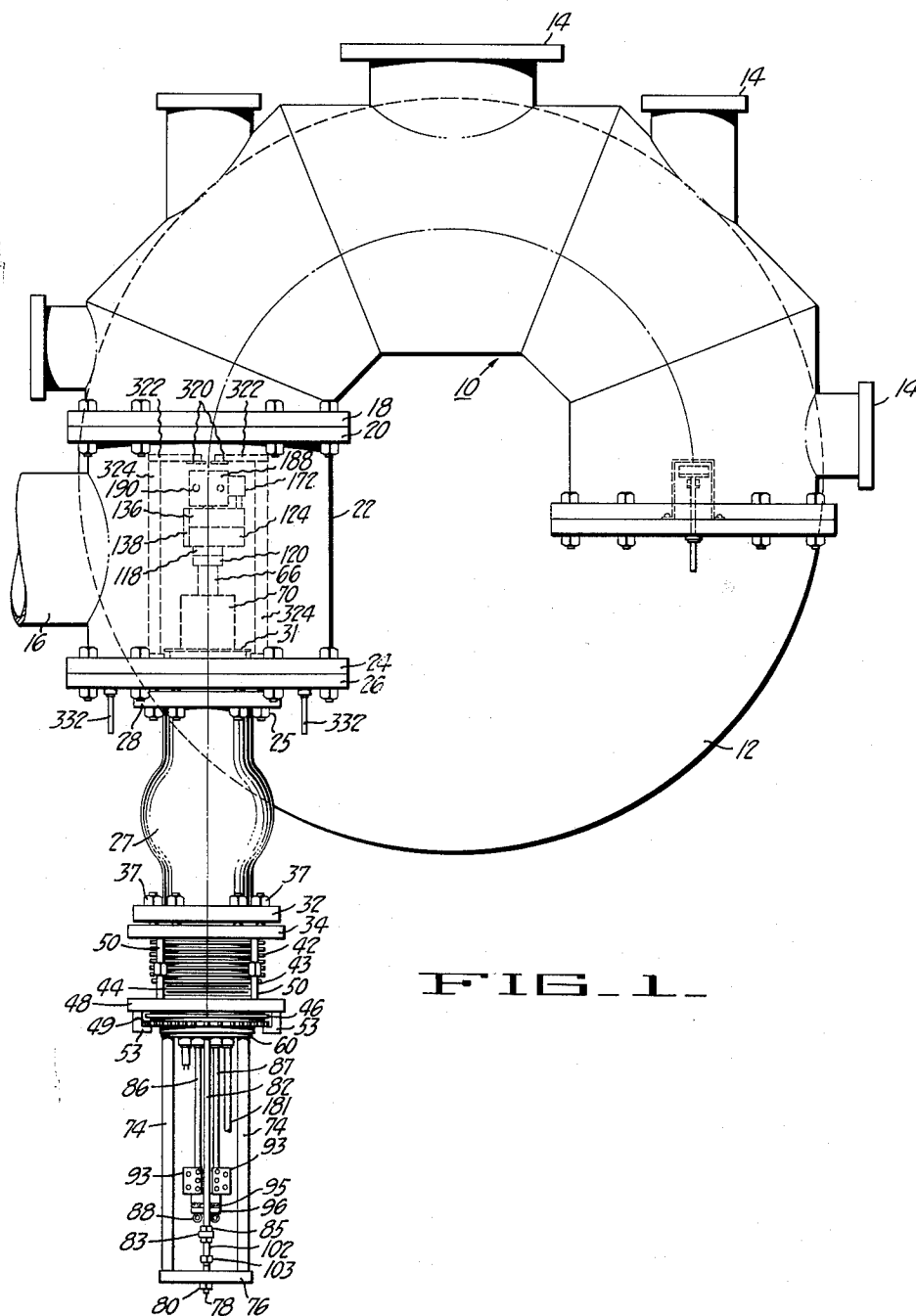


FIG. 1

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6 Sheets-Sheet 2

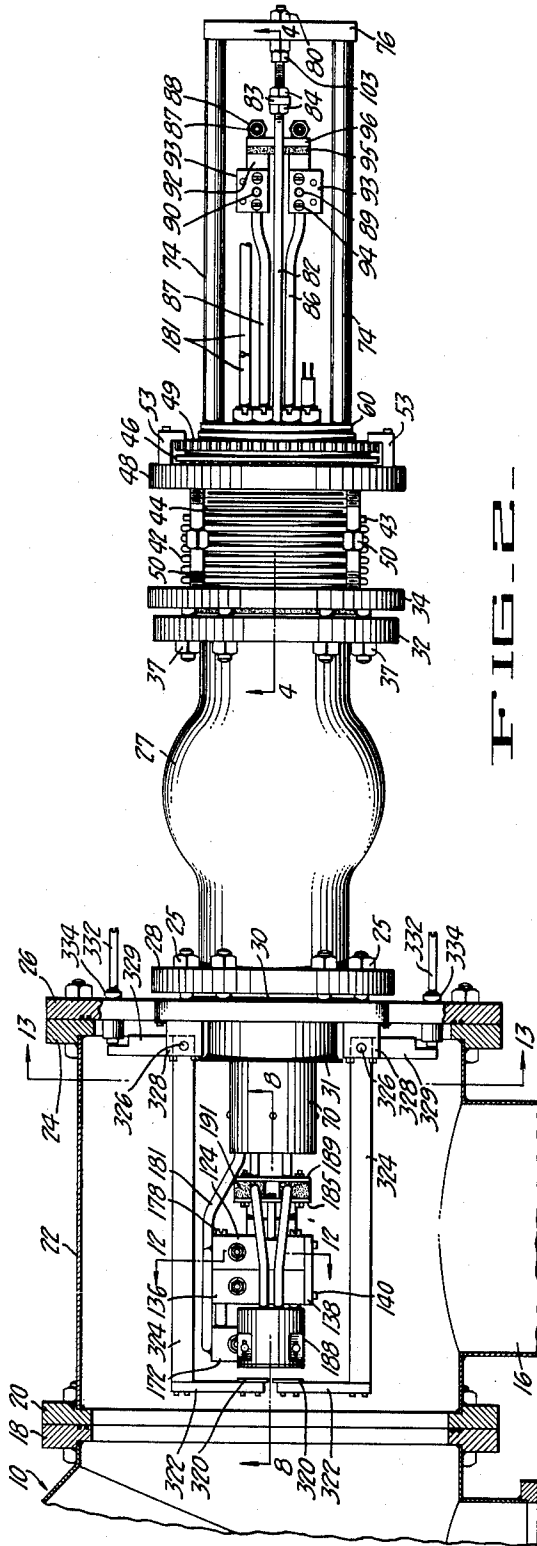


FIG. 2

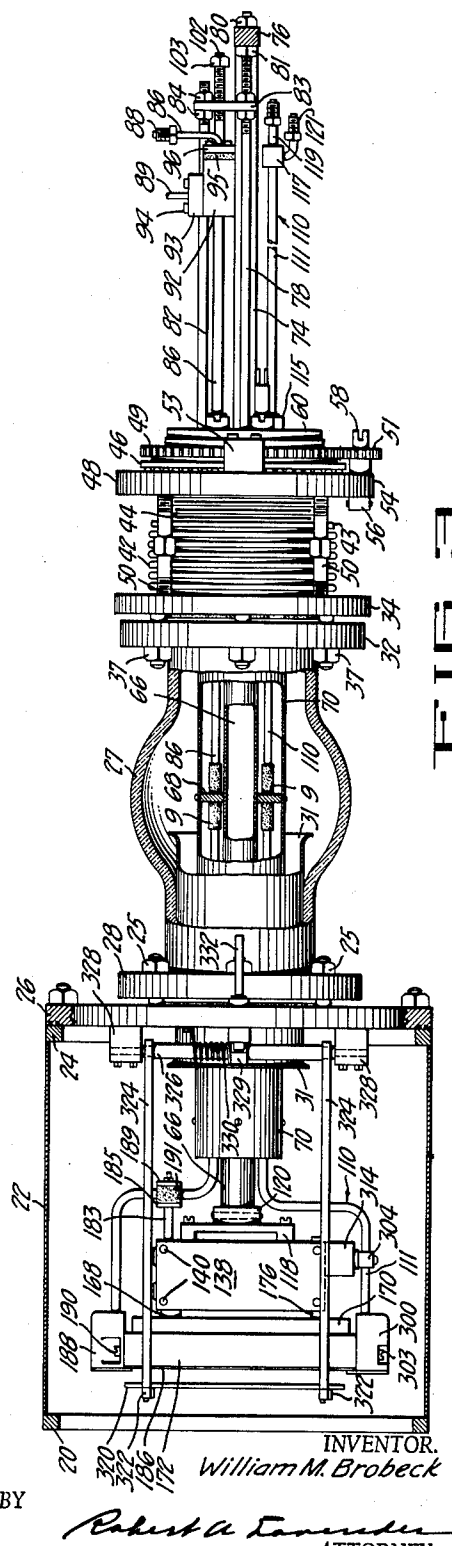


FIG. 3

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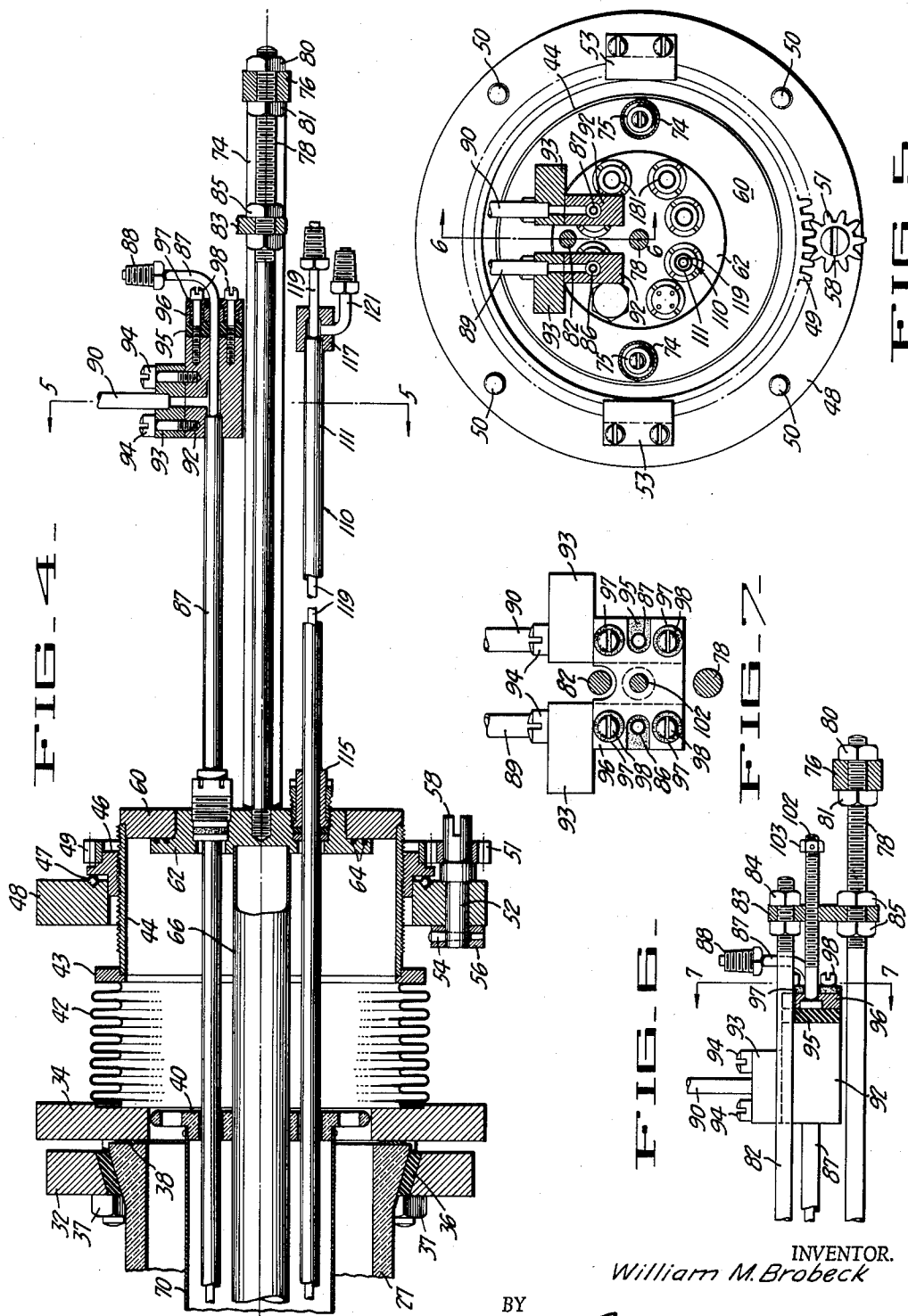
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2,737,589

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6 Sheets-Sheet 3



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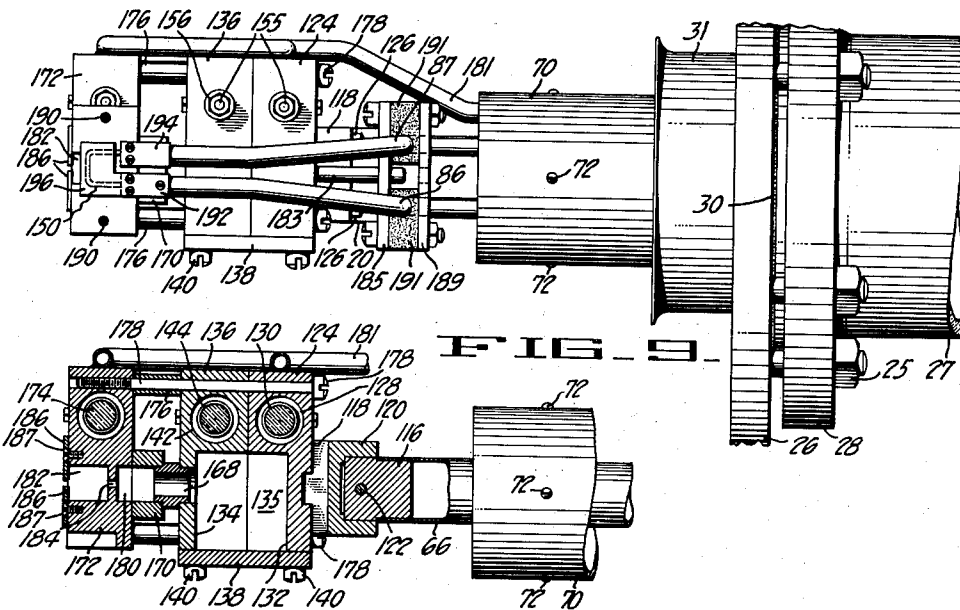


FIG. 10

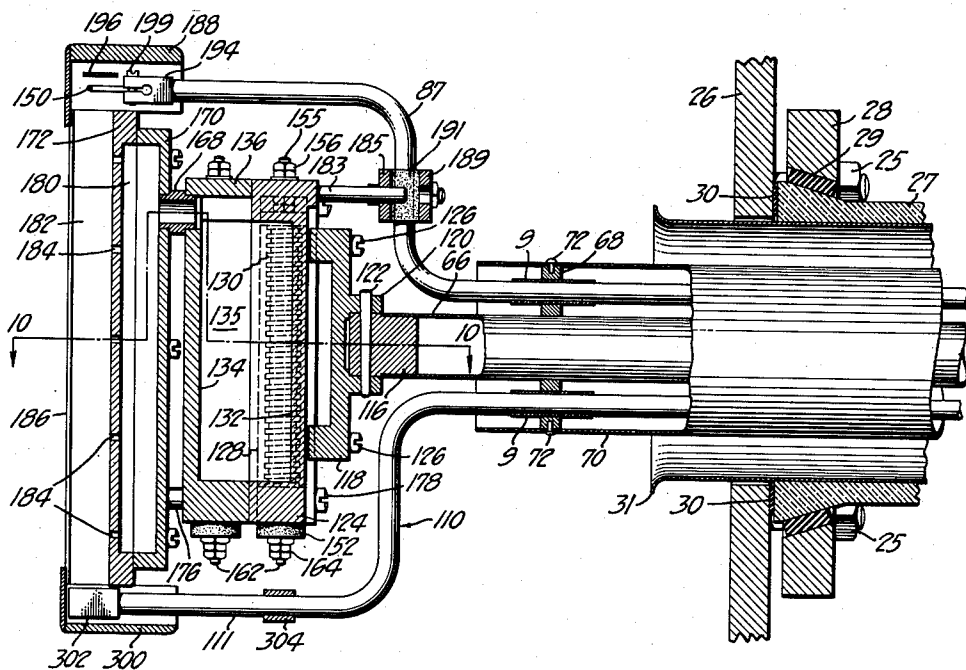


FIG. 8

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FIG. 11

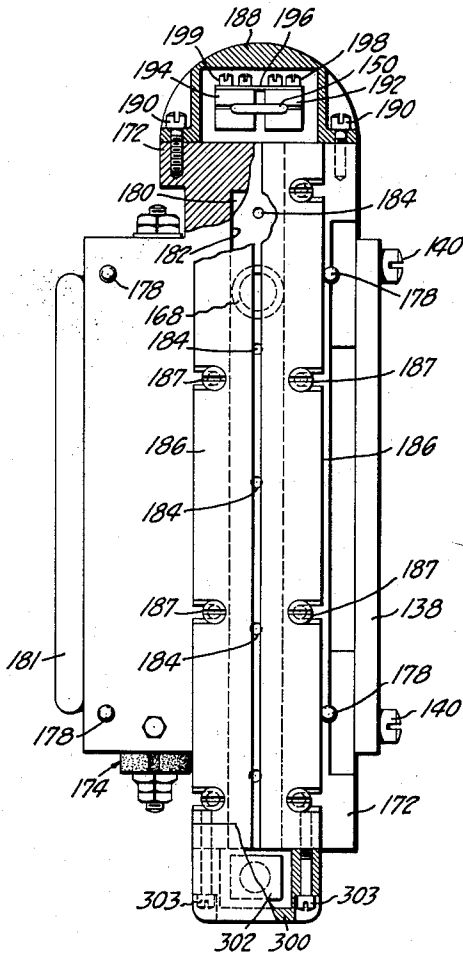


FIG. 12

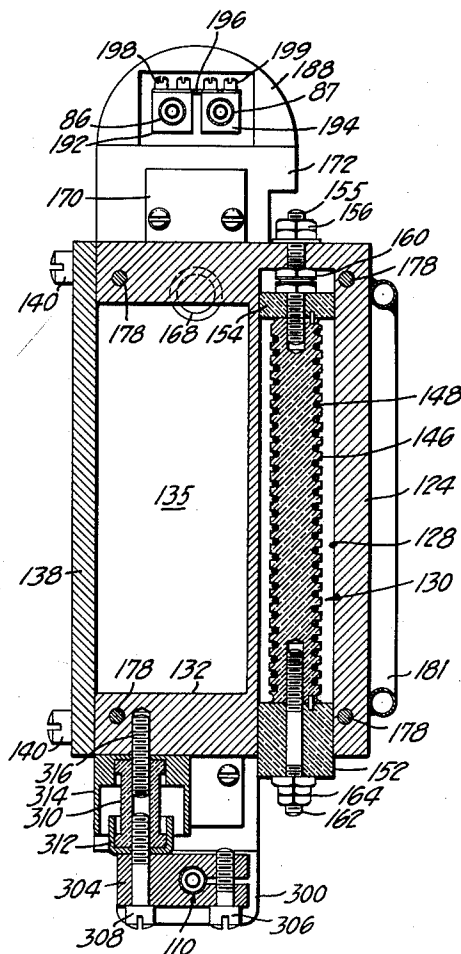
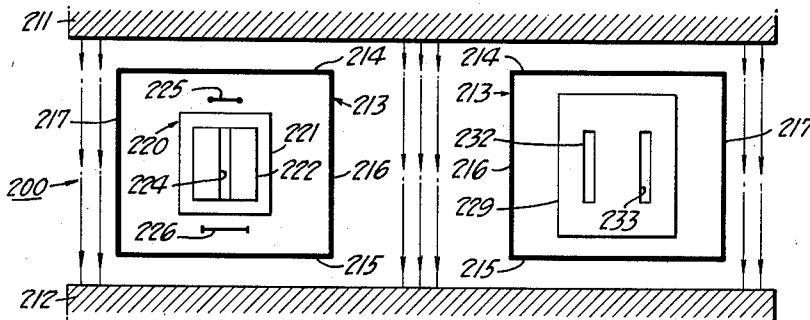


FIG. 15

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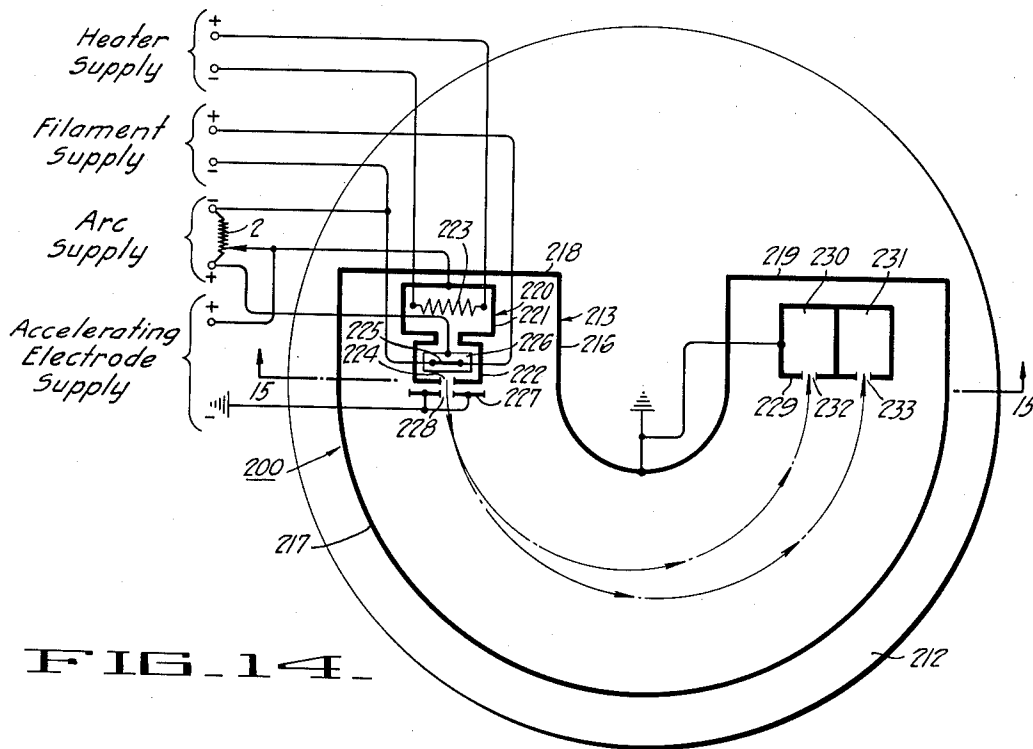
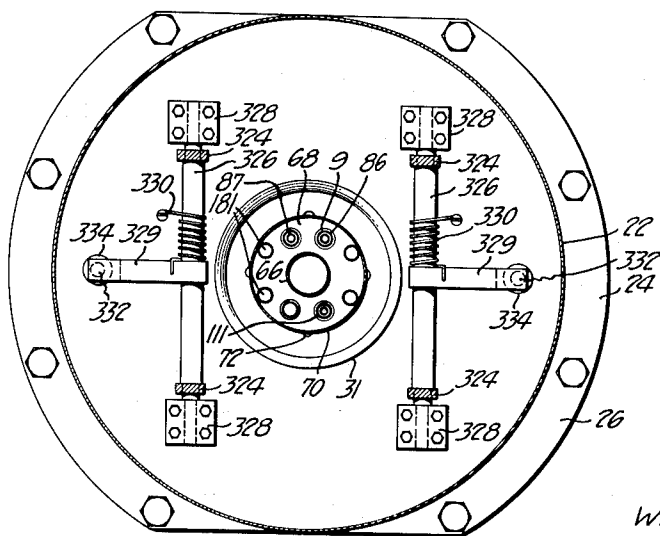
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2,737,589

ION SOURCE FOR A CALUTRON

Filed Feb. 19, 1945

6 Sheets-Sheet 6



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ION SOURCE FOR A CALUTRON

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Application February 19, 1945, Serial No. 578,791

26 Claims. (Cl. 250—41.9)

The present invention relates to the art of treating a polys isotopic substance to produce a plurality of segregable masses wherein the distribution of the constituent isotopes has been altered so that one of the masses produced is enriched with respect to at least one isotope. The purpose of such treatment is to obtain a product characterized by an enhancement of the percentage of a selected isotope. More specifically, the invention relates to the device known in the art as a "calutron," a term which has been defined as "any apparatus or machine wherein isotope separation or enrichment is achieved on a large scale yielding commercially useful quantities of one or more isotopes, by appropriate separative action on gaseous ions with electrostatic or electromagnetic means or combinations of them."

The foregoing definition has been taken from an application for Letters Patent of the United States, Serial No. 557,784, filed on October 9, 1944, by Ernest O. Lawrence, now Patent No. 2,709,222 and may appropriately be used in connection with the present invention.

It may be stated in passing, however, that by projecting a beam of positive ions of a vaporized or gaseous polys isotopic substance through a magnetic field acting normally to the path of the beam, the beam is caused to follow a curve wherein the ions of the heavier isotope tend to concentrate in the region adjacent the outer periphery and the ions of the lighter isotope congregate in the region adjacent the inner periphery. In other words, ions of greater mass travel along a curve of greater radius than the ions of lesser mass. By disposing suitable pockets or collectors in the path of the beam, preferably 180° from the source of the beam, it is possible to collect at least two masses, one of which is enhanced with respect to one isotope while the other is correspondingly impoverished with respect thereto.

Of course there are many conditions which must be fulfilled before a calutron can be successfully operated. For example, the ion source, the region surrounding the beam, and the collector must be incorporated in a reduced pressure system evacuated to a pressure of the order of 10^{-5} to 10^{-4} mm. Hg. Such matters will be herein referred to but briefly, inasmuch as it is with the ion beam producing mechanism, or "source," that the present invention is concerned.

A source for a calutron includes a chamber for holding a quantity of material capable of being vaporized, a heater for the chamber, a cathode and anode for establishing a stream of electrons, and accelerating electrodes; the whole being so arranged that when the circuits are closed, the material vaporizes and is drawn through the electron stream where ionization takes place. The ions are then drawn through a slit by the accelerating electrodes to form a beam.

The most important object of the invention is to produce an ion beam more efficiently than has heretofore been accomplished and to cause the ionization of a greater percentage of the vaporized material.

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Another object of the invention is to provide an ion beam-producing mechanism which is of simple, rugged construction, and capable of continued operation without undue wear.

Another object of the invention is to provide a calutron ion source having an improved electrode arrangement productive of a uniform and copious supply of ions.

A further object of the invention is to provide an improved mount for a calutron ion source in which the vacuum seal is improved and the necessary critical adjustments of the elements facilitated.

One feature of the invention resides in the provision of independent heating elements for the charge or vaporizing chamber and for the ionization chamber.

Another feature of the invention comprises a water-cooled cathode capable of adjustment while the source is in operation.

Another feature of the invention consists of an insulated water-cooled anode and a hood arranged to protect the anode from extraneous materials, as well as to prevent the escape of vapor about the anode.

A further feature of the invention consists in accelerating electrodes mounted as unitary elements of the ion producing mechanism but separately adjustable.

Another feature of the invention resides in novel structure for tensioning the source mount against the calutron tank and improving the vacuum seal.

These and other objects and features of the invention will more readily be understood and appreciated from the following detailed description of a preferred embodiment thereof selected for purposes of illustration and shown in the accompanying drawings, in which:

Fig. 1 is a plan view showing the general arrangement of a calutron;

Fig. 2 is a plan view of the source;

Fig. 3 is a view in side elevation of a source embodying the invention;

Fig. 4 is a view in cross section along the line 4—4 of Fig. 2;

Fig. 5 is a view in cross section along the line 5—5 of Fig. 4;

Fig. 6 is a view in cross section along the line 6—6 of Fig. 5;

Fig. 7 is a view in cross section along the line 7—7 of Fig. 6;

Fig. 8 is a view in cross section along the line 8—8 of Fig. 2;

Fig. 9 is a plan view of the inner portion of the source;

Fig. 10 is a view in cross section along the line 10—10 of Fig. 8;

Fig. 11 is a view in end elevation of the device;

Fig. 12 is a view in cross section along the line 12—12 of Fig. 2;

Fig. 13 is a view in cross section along the line 13—13 of Fig. 2;

Fig. 14 is a diagrammatic plan view of a representative calutron in which there may be incorporated an ion source embodying the present invention; and

Fig. 15 is a diagrammatic sectional view of the calutron taken along the line 15—15 in Fig. 14.

At the outset, it is noted that a "calutron" essentially comprises means for vaporizing a quantity of material containing an element that is to be enriched with a selected one of its several isotopes; means for subjecting the vapor to ionization, whereby at least a portion of the vapor is ionized causing ions of the several isotopes of the element to be produced; electrical means for segregating the ions from the un-ionized vapor and for accelerating the segregated ions to relatively high velocities; electromagnetic means for deflecting the ions along curved paths, the radii of curvature of the paths of the ions being proportional to the square roots of the masses

of the ions, whereby the ions are concentrated in accordance with their masses; and means for de-ionizing and collecting the ions of the selected isotope thus concentrated, thereby to produce a deposit of the element enriched with the selected isotope.

Referring now more particularly to Figs. 14 and 15 of the drawings, there is illustrated a representative example of a calutron 200 of the character noted, that comprises magnetic field structure including upper and lower pole pieces 211 and 212, provided with substantially flat parallel spaced-apart pole faces, and a tank 213 disposed between the pole faces of the pole pieces 211 and 212. The pole pieces 211 and 212 carry windings, not shown, which are adapted to be energized in order to produce a substantially uniform and relatively strong magnetic field therebetween, which magnetic field passes through the tank 213 and the various parts housed therein. The tank 213 is of tubular configuration, being substantially crescent-shaped in plan, and comprising substantially flat parallel spaced-apart top and bottom walls 214 and 215, upstanding curved inner and outer side walls 216 and 217, and end walls 218 and 219. The end walls 218 and 219 close the opposite ends of the tubular tank 213 and are adapted to be removably secured in place, whereby the tank 213 is hermetically sealed. Also, vacuum pumping apparatus, not shown, is associated with the tank 213, whereby the interior of the tank 213 may be evacuated to a pressure of the order of 10^{-5} to 10^{-4} mm. Hg. Preferably, the component parts of the tank 213 are formed of steel, the top and bottom walls 214 and 215 thereof being spaced a short distance from the pole faces of the upper and lower pole pieces 211 and 212 respectively, the tank 213 being retained in such position in any suitable manner, whereby the top and bottom walls 214 and 215 constitute in effect pole pieces with respect to the interior of the tank 213, as explained more fully hereinafter.

The removable end wall 218 suitably supports a source unit 220 comprising a charge receptacle 221 and a communicating arc-block 222. An electric heater 223 is arranged in heat exchange relation with the charge receptacle 221 and is adapted to be connected to a suitable source of heater supply, whereby the charge receptacle 221 may be appropriately heated, the charge receptacle 221 being formed of copper or the like. The arc-block 222 is formed of copper and is substantially C-shaped in plan, an upstanding slot 224 being formed in the wall thereof remote from the charge receptacle 221. Thus, the arc-block 222 is of hollow construction, the cavity therein communicating with the interior of the charge receptacle 221.

Also, the removable end wall 218 carries a filamentary cathode 225 adapted to be connected to a suitable source of filament supply, the filamentary cathode 225 overhanging the upper end of the arc-block 222 and being arranged in alignment with respect to the upper end of the cavity formed therein. Further, the removable end wall 218 carries an anode 226 disposed below the lower end of the arc-block 222 and arranged in alignment with respect to the lower end of the cavity formed therein. The tank 213 is grounded. The filamentary cathode 225 and the cooperating anode 226 are adapted to be connected to a suitable source of arc supply.

Further, the removable end wall 218 carries ion accelerating structure 227 formed in part of carbon or graphite, and disposed in spaced-apart relation with respect to the wall of the arc-block 222 in which the slot 224 is formed. More specifically, a slit 228 is formed in the ion accelerating structure 227 and arranged in substantial alignment with respect to the slot 224 formed in the wall of the arc-block 222. A suitable source of accelerating electrode supply is adapted to be connected between the arc-block 222 and the ion accelerating structure 227, the positive and negative terminals of the supply mentioned being respectively connected to the arc-block

222 and to the ion accelerating structure 227. Further, the negative terminal of the ion accelerating potential is grounded.

The removable end wall 219 suitably supports a collector block 229 formed of stainless steel or the like and provided with two laterally spaced-apart cavities or pockets 230 and 231 which respectively communicate with aligned slots 232 and 233 formed in the wall of the collector block 229 disposed remote from the removable end wall 219. It is noted that the pockets 230 and 231 are adapted to receive two constituent isotopes of an element which have been separated in the calutron 200, as explained more fully hereinafter.

It will be observed from an inspection of the schematic circuit diagram in Fig. 14 that the negative terminal of the filament supply is tied to the negative side of the arc supply which is bridged by a potentiometer 2, the center tap of which is connected to the arc-block and to the positive side of the supply for the accelerating electrodes. The accelerating electrodes and the negative side of the supply thereto are at ground potential. Consequently, the arc-block may conveniently be maintained slightly less positive than the anode or at the same potential as the anode. The filament voltage may be of the order of 4 volts, and the arc voltage may be of the order of 100 volts; the accelerating voltage is considerably higher and may be of the order of ten kilovolts. The voltages are not critical and the values above given are merely illustrative of one combination which has been successfully operated.

Considering now the general principle of operation of the calutron 200, a charge comprising a compound of the element to be treated is placed in the charge receptacle 221. The end walls 218 and 219 are securely attached to the open ends of the tank 213, whereby the tank 213 is hermetically sealed. The various electrical connections are completed and operation of the vacuum pumping apparatus, not shown, associated with the tank 213 is initiated. When a pressure of the order of 10^{-5} to 10^{-4} mm. Hg is established within the tank 213, the electric circuits for the windings, not shown, associated with the pole pieces 211 and 212 are closed and adjusted, whereby a predetermined magnetic field is established therebetween traversing the tank 213. The electric circuit for the heater 223 is closed, whereby the charge in the charge receptacle 221 is heated and vaporized. The vapor fills the charge receptacle 221 and is conducted into the communicating cavity formed in the arc-block 222. The electric circuit for the filamentary cathode 225 is closed, whereby the filamentary cathode is heated and rendered electron emissive. Then the electric circuit between the filamentary cathode 225 and the anode 226 is closed, whereby an arc discharge is struck therebetween, electrons proceeding from the filamentary cathode 225 to the anode 226. The electrons proceeding from the filamentary cathode 225 break up the molecular form of the compound of the vapor to a considerable extent, producing positive ions of the element that is to be enriched with the selected one of its isotopes.

The electric circuit between the arc-block 222 and the ion accelerating structure 227 is completed, the ion accelerating structure 227 being at a high negative potential with respect to the arc-block 222, whereby the positive ions in the arc-block 222 are attracted by the ion accelerating structure 227 and accelerated through the voltage impressed therebetween. More particularly, the positive ions proceed from the cavity formed in the arc-block 222 through the slot 224 formed in the wall thereof, and across the space between the ion accelerating structure 227 and the adjacent wall of the arc-block 222, and thence through the slit 228 formed in the ion accelerating structure 227 into the interior of the tank 213. The high-velocity positive ions form a vertical upstanding ribbon or beam proceeding from the cavity formed

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in the arc-block 222 through the slot 224 and the aligned slit 228 into the tank 213.

The collector block 229 and the tank are grounded, the same being true of the ion accelerating structure 227, whereby there is an electric-field-free path for the high-velocity positive ions disposed between the ion accelerating structure 227 and the collector block 229 within the tank 213. The high-velocity positive ions entering the adjacent end of the tank 213 are deflected from their normal straight-line path and from a vertical plane passing through the slot 224 and the aligned slit 228, due to the effect of the relatively strong magnetic field maintained through the space within the tank 213 through which the positive ions travel, whereby the positive ions describe arcs, the radii of which are proportional to the square roots of the masses of the ions and consequently of the isotopes of the element mentioned. Thus, ions of a relatively light isotope of the element describe an interior arc of relatively short radius and are focused through the slot 232 into the pocket 230 formed in the collector block 229; whereas ions of a relatively heavy isotope of the element describe an exterior arc of relatively long radius and are focused through the slot 233 into the pocket 231 formed in the collector block 229. Accordingly, the relatively light ions are collected in the pocket 230 and are de-ionized to produce a deposit of the relatively light isotope of the element therein; while the relatively heavy ions are collected in the pocket 231 and are de-ionized to produce a deposit of the relatively heavy isotope of the element therein.

After all of the charge in the charge receptacle 221 has been vaporized, all of the electric circuits are interrupted and the end wall 218 is removed so that another charge may be placed in the charge receptacle 221 and subsequently vaporized in the manner explained above. After a suitable number of charges have been vaporized in order to obtain appropriate deposits of the isotopes of the element in the pockets 230 and 231 of the collector block 229, the end wall 219 may be removed and the deposits of the collected isotopes in the pockets 230 and 231 in the collector block 229 may be reclaimed.

Of course, it will be understood that the various dimensions of the parts of the calutron 200, the various electrical potentials applied between the various electrical parts thereof, as well as the strength of the magnetic field between the pole pieces 211 and 212, are suitably correlated with respect to each other, depending upon the mass numbers of the several isotopes of the element that is to be treated therein.

The present invention pertains particularly to the mechanism for producing the beam of ions and comprises a novel combination of elements effective to bring about a higher yield, a more stable beam, and a more thorough ionization of the vaporized material.

In Fig. 1, the reference character 10 designates a tank arranged roughly in the form of a C and composed of a series of trapezoidal segments of suitably heavy material such as brass, or steel, welded or bolted together to provide a substantially airtight structure. At intervals, the walls of the tank are interrupted by viewing ports 14 through which the operation of the device may be observed, particularly the path of the ion beam as revealed by accompanying luminous phenomena. The tank 10 is disposed between the pole pieces of a large magnet, as previously described in connection with Figs. 14 and 15. The lower pole piece is indicated at 12.

At the source end, the tank proper terminates in a centrally apertured flanged header 18 to which is bolted a section 22 terminating at its inner end in a cooperating centrally apertured flanged plate 20 and having in one side an outlet 16 coupled to pumping apparatus (not shown) by means of which the tank may be evacuated. The outer end of the tank section 22 is provided with an integral apertured flanged face plate 24 to which the

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source unit structure is secured by means of a cooperating flanged member, or face plate 26. As used herein, the terms "outer" and "inner" relate to locations with respect to the tank 10.

The supporting structure for the source unit will now be discussed. As best shown in Fig. 8, a hollow bulbous insulator 27 of very heavy glass or ceramic material terminating at either end in reduced neck portions provided with beveled annular shoulders is held against the face of the plate 26 by means of an annular collar 28 and a cooperating ring gasket 29 interposed between the collar 28 and the annular shoulder on the end of the glass insulator 27. Another ring gasket 30 fits between the faces of the insulator 27 and the plate 26 to effect a vacuum seal. Secured to the face of the plate 26 is an annular series of studs which penetrate apertures in the collar 28 and are threaded to receive nuts 25 serving to urge the collar 28 toward the outer face of the plate 26, thus clamping the insulator 27 tightly against the plate 26 and compressing the gasket 30 to form a vacuum seal. A cylindrical shield 31 of light metal is disposed to fit partially within the insulator 27 and to extend through an aperture in the plate 26 a short distance into the interior of the tank 10. The shield 31, together with other apparatus later to be described, minimizes wear on the insulator 27, as will hereinafter be discussed.

A centrally apertured mounting plate 34 shown in Fig. 4, preferably of heavy gauge steel, brass or other suitable material, supports the source unit and is secured to the outer end of the insulator 27 in the same manner in which the inner end of the insulator 27 is secured to the plate 26. That is to say, the mounting plate 34 carries spaced studs which penetrate apertures in an annular collar 32 disposed about the outer shoulder end of the insulator 27 but spaced therefrom by a gasket 36. The studs are threaded to receive nuts 37 by means of which the collar 32 and the insulator 27 are urged toward the face of the mounting plate 34. A gasket 38 is interposed between the insulator 27 and the plate 34 and serves as a vacuum seal.

Fitting loosely within an annular aperture in the plate 34 is a ceramic disk 40 provided with a number of apertures and having an annular shouldered portion on its inner surface to which is secured one end of a tubular shield 70 of light metal, the shield 70 having lesser diameter than that of the shield 31 and being substantially concentric therewith. Welded to the outer surface of the mounting plate 34 is an expansible bellows 42 of copper or other suitable light gauge flexible metal. The outer end of the bellows 42 is provided with an annular header 43 shouldered internally to receive a metal sleeve 44 provided on its outer surface with fine threads cooperating with an internally threaded bushing 46. The bushing 46 is welded or otherwise secured to a ring gear 49. A heavy plate 48, disposed about the sleeve 44, has on its outer face a raceway receiving ball bearings 47 against which the inner face of the bushing 46 bears. The plate 48 provides a journal for a stub shaft 52 which carries a pinion 51 meshing with the ring gear 49. The pinion 51 is keyed to the shaft 52 which is secured to the plate 48 by a pin 54 piercing the end of the shaft 52 and passing through a collar 56. The inner end of the shaft 52 is enlarged as shown at 58 and provided with a cooperating slot. A screw driver may be inserted in the slot to turn the pinion 51 and thus cause rotation of the ring gear 49 and the bushing 46 which is fast thereto. A pair of L-shaped keepers 53 are secured to the plate 48 and bear on the outer surface of the ring gear 49, as noted in Fig. 2.

Spaced at 90° intervals between the mounting plate 34 and the plate 48 are four turnbuckles 50 serving to provide a tilting adjustment for the plate 48 and its associated mechanism with respect to the mounting plate 34 and more particularly with respect to the axis of the centrally located aperture in the plate 34. By tightening an adjacent pair of turnbuckles 50 and loosening the other

pair, a slight tilting movement is obtained. It should be stated at this time that this adjustment varies the position of the source of the ion beam within the tank and that the nature of the device is such that only minute changes in position are desired, or, indeed, permissible.

Inasmuch as the plate 48 is held in fixed adjusted position by the turnbuckles 50, the rotation of the ring gear 49 causes the sleeve 44 to move rectilinearly to expand or contract the bellows 42, depending upon the direction of the torque applied to the shaft 52.

Carried on the end of the sleeve 44, as shown in Fig. 4, is a disk 60 having an annular centrally located passage and an annular shouldered portion fitting inside the end of the sleeve 44. The disk 60 is welded or otherwise suitably secured to the sleeve 44. Received in the aperture of the disk 60 is an annular plug 62 having an inner flanged rim seating against the inner face of the disk 60 and provided with a pair of annular recesses in which are received ring gaskets 64 adapted to form a vacuum seal when the plug is drawn against the disk 60 by means of structure hereafter to be described. A hollow tubular stem 66 of light gauge metal is secured at one end to the inner face of the plug 62 and extends inwardly into the tank 10, passing through an aperture in the ceramic spacer 40 and substantially coaxial with the insulator 27 and the shield 31. Two brass disks 68 are apertured to receive the stem 66 and carry a cylindrical metal shield 70 secured thereto by means of screws 72. The opposite end of the shield 70 is pinned to the ceramic spacer 40. The insulator 27, the shield 31, the shield 70, and the stem 66 are substantially concentric.

The inner ends of a pair of hollow tubular arms 74 fit over studs or bosses 75 screwed to the outer surface of the disk 60 and are secured at their outer ends to a bridge member or cross head 76 centrally apertured to receive a rod 78 screwed into the plug 62. The outer end of the rod 78 is threaded to receive a nut 80 which bears against the outer face of the bridge member 76. It will now be evident that when the nut 80 is tightened on the rod 78, pressure is exerted through the arms 74 against the disk 60 and balanced by pressure of the plug 62 against the inner face of the disk 60. By this means, the gaskets 64 are compressed and a vacuum seal is maintained between the plug 62 and the disk 60. A lock nut 81 carried by the rod 78 may be tightened against the bridge 76 and serves to preserve the adjustment obtained by manipulation of the nut 80.

The rod 78 also carries a pair of lock nuts 85 between which is clamped a bracket 83 apertured to receive and engage in screw-threaded relation a rod 102 on the outer end of which is a nut 103 pinned to the rod 102. The bracket 83 also receives support from a rod 82 secured at one end to the outer face of the plug 62 and threaded at its outer end to receive a pair of lock nuts 84 between which the bracket is clamped.

As shown in Figs. 6 and 7, the inner end of the rod 102 is enlarged and received in a recess formed in the inner face of a block 96 which bears against a gasket 95 of insulating material. The inner face of the gasket 95 bears against the blocks 92, and the elements 92, 95, 96, and 97 are clamped together by means of a plurality of screws 98; around the shank of each screw is an insulating collar 97. As shown particularly in Figs. 4 and 5, the blocks 92 and the members 95, 96, and 97 are apertured to receive a pair of conductors or leads 86 and 87 in the form of squirt tubes. In other words, the conductor is cooled by a flow of water entering through an inner tube and passing out through an outer concentric tube. In Figs. 4 and 5, the conductors 86 and 87 are shown to be provided with water inlet connections 88 which emerge from the outer end of the blocks 92 and water outlet tubes 89 and 90 which are received in the top of the blocks 92. A pair of caps 93 are secured to the top of the blocks 92 by means of screws 94, the outlet tubes 89 and 90 being secured in the caps 93. That is to say, the water outlet

tubes 89 and 90 may be disconnected merely by removing the screws 94 and lifting off the caps 93.

The conductors 86 and 87 carry at their inner ends a filamentary cathode 150, as will hereinafter be more fully explained, and pass through vacuum seals at the plug 62, and through the spacers 40 and 68, provision being made in each case for a sliding fit. By rotation of the rod 102, conveniently obtained by applying a wrench to the nut 103, the blocks 92 and their associated elements including the conductors 86 and 87 are translated rectilinearly to effect horizontal adjustment of the cathode 150.

A single squirt tube conductor 110 is supported by a vacuum seal plug 115 threaded into the plug 62 and terminating at its outer end in a block 117 apertured to receive the outer envelope or water jacket 111 of the anode conductor 110, the inner water inlet tube 119, and an outlet connection 121. All of the conductors and squirt tubes are insulated from each other and from the brass disks 68 by means of glass sleeves 9.

The structure described in the foregoing paragraphs serves to mount the ion-producing mechanism in the tank. The elements of the mechanism itself will now be discussed. The tubular stem 66 carries at its inner end a plug 116 rigidly secured thereto and received in an annular socket 120 which is integral with a support frame 118. The frame and socket are secured to the plug 116 by means of a pin 122 passing through the socket and the plug. A block 124 is secured to the frame 118 by means of four screws 126, and is provided with a cylindrical bore 128 within which is disposed a coil electric heater 130, the connections to which are not shown but which may conveniently be led out of the tank within the shield 70 along with the leads 86 and 87. The block 124 is also cut away to form a rectangular recess 132 in the inner face thereof. A similar recess 134 is formed in a contiguously disposed block 136, the two recesses 132 and 134 being closed by a side plate 138, secured to the blocks by screws 140. The walls of the two recesses 132 and 134, and the inner wall of the side plate 138 define a chamber 135. The block 136 is provided with a cylindrical bore 142 within which is received another coil heater 144.

The coil heater as used in conjunction with the apparatus comprising the invention includes the elements most clearly shown in Fig. 12 as constituting the coil heater 130 contained in the block 124. A core 146 of ceramic refractory material, and of rod-like form is provided with a spiral grooving adapted to receive a coil 148 of high resistance wire, for example, nichrome, served by means of suitable conductors not shown. At the upper end of the core 146 is a disk plug 154 of insulating material contained in the upper portion of the recess of the bore 128. A threaded rod 155 passes through the top of the block 124 and is screwed into the top of the core 146. By means of lock nuts 156 and 160, the rod 155 is rigidly mounted in the block 124. At its lower end the bore 128 is open and receives a plug 152 of insulating material pierced by a rod 162 screwed into the lower end of the core 146; a pair of lock nuts 164 clamp the plug 152 against the bottom of the core 146. The plugs 152 and 154 have greater diameters than that of the core 146 and serve to space the core 146 and the coil 148 from the walls of the block 124.

The inner wall of the recess 134 in the block 136 is provided with an aperture into which is inserted one reduced end of a nipple 168 which, in turn, fits into a bore formed at the outer wall of a hollow, rectangular, box-shaped member 170. A third block 172 is clamped against the member 170 by means of bolts 178 passing through the blocks 124 and 136 and threaded into the block 172. Each bolt 178 is provided with a spacer sleeve 176 compensating for the width of the nipple 168 and the member 170. The member 170 is also bolted to the inner face of the block 172. The block 172 is bored to receive a coil heater 174 similar in construction to the heaters

130 and 144. In the outer face of the block 172 is an elongated, narrow rectangular recess forming with the member 170 a chamber 180 communicating by means of the nipple 168 with the chamber 135 formed by the recesses cut into the blocks 124 and 136. The block 172 is also provided with an elongated rectangular chamber 182 disposed opposite the chamber 180. That portion of the block lying between the chambers 180 and 182 is provided with a number of apertures or conduits 184 spaced symmetrically at intervals from top to bottom of the chambers 180 and 182. The inner wall of the chamber 182 is formed by a pair of face plates 186, screwed to the inner face of the block 172 by screws 187, and spaced apart to form a narrow elongated slit running the length of the chamber 182.

Secured to the top of the block 172 by screws 190 is a hooded hollow cap 188 within which the cathode leads 86 and 87 terminate in a pair of spaced clamp blocks 192 and 194, fitted to receive clamping screws 198 and 199 by means of which the filamentary cathode 150 is clamped. The screws 198 also serve to clamp a light metal shield 196 to the top of the block 192, the shield 196 having the form of a rectangle with a tab on one corner for engagement with the screws 198. The cathode 150 may be tungsten or any of the other materials commonly used in electron discharge devices. The shield 196 is arranged to overlie the cathode 160 and serves to repel electrons discharged upwardly from the cathode 150 by reason of the fact that it is operated normally at the same potential as the cathode. It will be understood that the shield 196 may be mounted in any other suitable manner and operated by means of proper insulation and connections, at any other desired potential.

Inasmuch as high temperatures are generated during the operation of the device, and particularly in the blocks 124, 136 and 172, a cooling system is provided in the form of a conduit 181 secured to one end of the blocks and looped to form a closed system through which a cooling fluid may be passed. Preferably the loop 181 is spot welded to the blocks, although other suitable means of securing it may be utilized.

The block 124 is provided at its outer end with an outwardly projecting pin 183 adapted to receive a bracket 185 which in turn is bolted to a similar bracket 189. The bracket 185 slides in and out on the pin 183. Plugs 191 of insulating material are clamped between the brackets 185 and 189 and are apertured to receive the cathode leads 86 and 87, the dimensions of the apertures being such that a relatively tight fit is obtained. Referring again to Figs. 4 to 7, it will be seen that when the rod 102 is turned to move the blocks 92 rectilinearly, the cathode leads 86 and 87 are correspondingly moved and the pin 183 will slide in the bracket 185. Finally, the cathode 150 is correspondingly moved, the combination of elements being such that the position of the cathode 150 with respect to the chamber 182 may be adjusted from the outside of the tank while the calutron is being operated.

A hollow hooded shield member 300 is secured to the bottom end of the block 172 by screws 303 and underlies the lower end of the chamber 182. Within the shield 300 is disposed a rectangular block anode 302 carried on the end of the squirt tube conductor 111 and spaced from the walls of the hood 300 and from the bottom face of the block 172. To secure rigid mounting for the anode 302, the anode lead 111 is passed through a clamp block 304 having a bolt 306 which may be loosened to permit adjustment of the lead 111 and then tightened to maintain it in fixed position. The block 304 is provided with a vertical aperture for the reception of a bolt 308 which engages an elongated plug 310 of insulating material provided with an axial screw threaded bore. A cup-shaped shield 312 of light gauge metal embraces the lower end of the plug 310 and is held in place between the plug 310 and the upper surface of the block

304. Embracing the upper end of the plug 310 and extending downwardly beyond the upper end of the shield 312 is an inverted cup-shaped metal shield or hood 314 larger in diameter than the shield 312. A threaded rod 316 is screwed to the bottom of the block 124 and also screwed to the axial bore of block 310, the shield 314 thus being clamped between the lower surface of the block 124 and the upper surface of the plug 310. The combination of the plug 310 and the shields 312 and 314 is commonly referred to, for the sake of brevity, as a "flower pot" insulator. Its function is to provide adequate insulation between the support block 304 and the block 124 and thus to provide an adequate, well-insulated support for the anode rod 111.

Inasmuch as the effect of the magnetic flux between the pole pieces is to collimate vertically any electron discharges occurring between them, it follows that there will be no arc extending horizontally between adjacent portions of the shields 312 and 314, the only path possible extending vertically from the ends of the shields. The spacing is sufficient to prevent a discharge in a vertical direction. The overlapping arrangement of the shields prevents vapor from reaching the insulator plug 310 and thus eliminates short circuits between the block 124 and the support 304 which might otherwise occur as the result of the condensation of vapor thereon.

The chamber 135 is partially filled with a charge of material to be vaporized. When the heater circuit is closed and vaporization takes place in the chamber 135, the effect of the vacuum in the tank 10 is to draw vapor from the chamber 135 through the nipple 168 and into the distribution chamber 180. From here the vapor is introduced into the chamber 182 through the widely spaced conduits 184, the result being that the vapor is substantially evenly distributed through the chamber 182. By the application of suitable potential to the cathode 150 and the anode 302 a stream of electrons is caused to move from the cathode to the anode. The electron stream bombards and ionizes the vapor in the chamber 182, the positions of the cathode and anode being such that the arc is directed along and just behind the slit formed by the face plates 186. To draw the ionized particles from the chamber 182 through the slit, accelerating electrodes operated at a highly negative potential are disposed in front of the ion producing mechanism contained in the blocks heretofore described.

The accelerating electrodes as shown in the Fig. 2 comprise a pair of plates 320, formed of tungsten, or the like, screwed to arms 322 and spaced apart to form a slot therebetween. The cross arms 322 are secured to the ends of four frame members 324 which are pivotally mounted on the inner face of the plate 26. That is to say, the inner ends of the frame members 324 are secured to a pair of hinge pins 326 received at their ends in pivot mounts 328 screwed to the inner face of the plate 26. Each pin 326 has secured to it a lever 329, thus forming the member 324, pin 326 and lever 329 into a conventional bell crank structure. Furthermore, each of the pins 326 carries a helical spring 330 bearing on the lever 329 and arranged to urge the lever 329 toward the face of the plate 26. Received in the plate 26 are screw-threaded pins 332 engaging internally screw threaded vacuum shield plugs 334. The outer ends of each of the pins 332 are slotted. By turning a pin 332 with a screw driver a lever 329 may be forced away from the plate 26 against the action of the spring 330 to cause two of the frame members 324 to bring one of the electrode plates 320 toward the other. By backing off on the pins 332, the operator may increase the spacing between the accelerating electrodes 320. The arrangement just described is advantageous in that the accelerating electrodes 320 are mounted as unitary parts of the ion source and are inserted and removed from the tank along with the other elements of the source. Both the ion source and the accelerating electrodes derive their principal support from the plate 26. Therefore, the

chance of the accelerating electrodes moving out of adjustment due to vibrations of the entire apparatus is minimized. Furthermore, the cathode and the accelerating electrodes may all be adjusted while the calutron is in operation and from approximately the same location. It will also be appreciated that each accelerating electrode 320 can be adjusted independently of the other and that said accelerating electrodes are connected to ground, as diagrammatically indicated in Figure 14.

It should be noted that the coil heaters 130, 144 and 174 are so arranged that the heating of the ionization chamber 182 may conveniently be independent of the heating of the vaporization chamber 135. This permits a more accurate control of the vaporization and ionization processes. The provision of the plurality of conduits interconnecting the distribution chamber and the ionization chamber greatly increases the percentage of vapor which is ionized in the device. It has been found that the location of the arc in the ionization chamber is highly critical and the provision of an adjustable cathode renders it possible to vary within limits the location of the electron stream, particularly with reference to the slits formed by the plates 186. This feature has made it possible to produce a more stable beam as well as to increase the percentage of material ionized.

The provision of water-cooling for the anode and the cathode serves to increase the life of the cathode and the anode and also of the wall of the cap block 188 disposed above the cathode 150. By providing restricted or limited passage between the charge chamber, the distribution chamber and the ionization chamber, the percentage of vapor ionized has been increased, since the vapor is thus caused to flow evenly and not permitted to concentrate at any one region.

It should further be pointed out that the hooded shield 300 serves to protect the anode from electron bombardment save from the direction of the cathode, a feature which increases the useful life of the anode. Furthermore, the shield 300 serves to prevent the escape of un-ionized vapor from the ionization chamber 182.

It should be well understood that the specific details of the device shown in the drawings and described at length herein may be considerably changed and readjusted without departing from the spirit of the invention as defined in the appended claims, and it must be emphasized that the device shown in the drawings represents only a preferred form in which the invention may be expressed.

Having now described and illustrated the features comprising my invention, what I claim as new and desire to secure by Letters Patent of the United States is:

1. In combination with an apparatus adapted to receive a beam of ions and having a wall defining an evacuated space a device for producing ions, which comprises walls defining a charge chamber, means for heating said charge chamber, walls defining an ionization chamber in communication with said evacuated space, means providing an electron discharge within said ionization chamber, independently controllable means for heating said ionization chamber, and a plurality of conduits leading from said charge chamber to said ionization chamber.

2. In combination with an apparatus adapted to receive a beam of ions and having a wall defining an evacuated space a device for producing ions, which comprises walls defining a charge chamber, walls defining an ionization chamber in communication with said evacuated space, means providing an electron discharge within said ionization chamber, walls defining an intermediate distribution chamber disposed between said charge and ionization chambers, means affording restricted passage from said charge chamber to said distribution chamber, a plurality of spaced conduits leading from said distribution chamber to said ionization chamber, and independent heaters for heating said charge chamber and said ionization chamber.

3. In combination with an apparatus adapted to receive a beam of ions and having a wall defining an evacuated

space a device for producing ions, which comprises walls defining an ionization chamber in communication with said evacuated space and containing an ionizable material, means providing an electron discharge within said chamber and including a cathode disposed adjacent one end of said chamber, a cap secured to said walls and overlying said cathode an electron shield interposed between said cathode and said cap and an anode disposed adjacent another end of said chamber.

4. In combination with an apparatus adapted to receive a beam of ions and having a wall defining an evacuated space a device for producing ions, which comprises walls defining an ionization chamber in communication with said evacuated space and containing an ionizable material, means providing an electron discharge within said chamber and including a movable cathode mounted adjacent one end of said ionization chamber, means for moving said cathode with respect to said chamber and a stationary water-cooled anode mounted at another end of said chamber and electrically insulated from the walls thereof.

5. In combination with an apparatus adapted to receive a beam of ions and having a wall defining an evacuated space a device for producing ions which comprises a block having an ionization chamber formed therein said chamber containing an ionizable material and communicating with said evacuated space, means for heating said block means providing an electron discharge within said chamber and including a cathode mounted adjacent one end of said chamber and a water-cooled anode mounted adjacent another end of said chamber and insulated electrically from said block.

6. In combination with an apparatus adapted to receive a beam of ions and having a wall defining an evacuated space a device for producing ions, which comprises walls defining a vaporizing chamber, means for heating said chamber, walls defining an ionization chamber in communication with said evacuated space, means affording limited passage between said chambers, means for heating said ionization chamber, and means providing an electron discharge within said ionization chamber for ionizing the vaporized material received from said vaporizing chamber.

7. In combination with an apparatus adapted to receive a beam of ions and having a wall defining an evacuated space a device for producing ions which comprises walls forming an ionization chamber in communication with said evacuated space and containing an ionizable material, means for controlling the temperature of said chamber, means providing an electron discharge within said ionization chamber and including a cathode mounted adjacent one end of said chamber and an anode disposed adjacent another end of said chamber, and a plurality of independent means for controlling the temperatures of said cathode and said anode.

8. An ion source for a calutron, which comprises walls defining an elongated ionization chamber containing an ionizable material, means providing an electron discharge within said chamber and including, a metal shield disposed adjacent one end of said chamber, a water-cooled anode mounted at the opposite end of said chamber, a water-cooled cathode disposed adjacent said shield and between the shield and the anode, and a cap secured to said walls and disposed to overlie said cathode.

9. A calutron structure having a wall defining an evacuated space, a mounting plate supported on said wall and provided with vacuum seals, an ion producing mechanism supported on said mounting plate, a pair of ion accelerating plates disposed in a position to accelerate ions from said producing mechanism, supporting frames for said plates pivotally mounted on said mounting plate, means passing through said seals on said mounting plate for moving said frames in one direction, and means for urging said frames in the opposite direction.

10. In combination with an apparatus having a wall defining an evacuated space, an ion source unit adapted to

be removably secured in vacuum-tight relation to said wall and comprising a mounting plate, means detachably sealing said plate to said wall, an ion producing mechanism adjustably secured to said plate, a pair of accelerating electrodes adjustably secured to said plate and adjusting means mounted upon said plate and operable externally of the apparatus for varying the position of said electrodes with respect to the outlet of said ion producing mechanism.

11. In combination with a calutron structure having a wall defining an evacuated space, an ion source unit adapted to be removably secured in vacuum-tight relation to said wall and comprising a mounting plate, means detachably sealing said plate to said wall, an ion producing mechanism secured to said plate, a plurality of accelerating electrodes mounted on said plate in cooperative relation with said ion producing mechanism, and means for independently adjusting the position of each accelerating electrode with respect to said mechanism, said means being mounted upon said plate and operable externally of the structure for varying the position of said electrodes with respect to the outlet of said ion producing mechanism.

12. In combination with a calutron structure having a wall defining an evacuated space, an ion source unit adapted to be removably secured in vacuum-tight relation to said wall and comprising a mounting plate, means detachably sealing said plate to said wall, an ion producing mechanism secured to said mounting plate, a pair of accelerating electrodes disposed in position to accelerate ions produced by said mechanism, support frames for said electrodes pivotally mounted on said plate, spring-loaded means for urging said frames in opposite directions, and means passing through said mounting plate in vacuum-tight relation thereto for forcing said frames to move in opposition to said spring-loaded means.

13. In combination with a calutron structure having a wall defining an evacuated space, an ion source unit adapted to be removably secured in vacuum-tight relation to said wall and comprising a mounting plate, means detachably sealing said plate to said wall, an ion producing mechanism secured to said mounting plate, an accelerating electrode disposed in position to accelerate ions produced by said mechanism, a support frame for said electrode pivotally mounted on said plate, means for urging said frame in one direction, and means passing through said plate in vacuum-tight relation thereto for forcing said frame in the opposite direction.

14. An adjustable ion source for a calutron, which comprises walls defining an elongated ionization chamber, means providing an electron discharge within said chamber and including a movable cathode disposed adjacent one end of said chamber, an accelerating electrode disposed in position to accelerate ions produced in said chamber, a mounting plate providing support for said walls, said cathode and said electrode; and means mounted on said plate and providing separate adjustments for said cathode and electrode with respect to said chamber.

15. In an ion source for a calutron including an ionization chamber containing an ionizable material, means providing an electron discharge within said chamber and including a cathode disposed adjacent one end of said chamber; an anode disposed adjacent another end of said chamber and electrically insulated from the walls of said chamber, and a hooded shield supported by the walls of said chamber and disposed about said anode.

16. In an ion source for a calutron including an ionization chamber containing an ionizable material, means providing an electron discharge within said chamber and including a cathode disposed adjacent one end of said chamber; an insulated water-cooled anode disposed adjacent another end of said chamber opposite said cathode, and a shield supported by the walls of the chamber and disposed to limit access to said anode except in the direction of said cathode.

17. In combination with a calutron having a wall defining an evacuated space, means for mounting an ion-producing mechanism within said calutron and including a hollow insulating member sealed at one end against said wall, and apertured closure attached to the other end of said insulating member and having an inturned rim, a flanged block adapted to be seated against said rim for sealing said aperture, a pair of supports projecting from said closure member, a bridge resting on said supports, a tension rod engaging said block and piercing said bridge, means for tensioning said rod and urging said flanged block against said rim, an ion producing mechanism mounted on and extending from one side of said block, and electrical conductors passing from the other side of said block through said block to said ion producing mechanism.

18. In combination with a calutron having a wall defining an evacuated space, means for mounting an ion-producing mechanism within said calutron and including a hollow insulating member sealed at one end against said wall, an apertured closure attached to the other end of said insulating member and having an inturned rim, a block adapted to seat against the inner face of said rim for sealing said aperture, a frame member secured to said closure member, a rod engaging said block and said frame member, means for tensioning said rod to draw said block against said rim, and ion producing mechanism supported within said tank by said block.

19. In combination with a calutron having a wall defining an evacuated space, means for mounting an ion-producing mechanism within said calutron and including a hollow insulating member sealed at one end against said wall, an apertured closure attached to the other end of said insulating member, a block engaging said closure member, a plurality of supports engaging said closure member, a bridge engaging said supports, a rod engaging said bridge and said block, means for tensioning said rod to seal the block against the closure member, and an ion producing mechanism supported within said tank by said block.

20. An ion source for a calutron, which comprises a tank, a support serving as an insulator and piercing a wall of said tank, an anode carried on said support and disposed within said tank a stiff conductor slidably mounted on said support, a cathode carried on one end of said stiff conductor within the tank, and means secured to said support outside said tank for moving said conductor and cathode rectilinearly.

21. An ion source for a calutron, which comprises a tank, a support serving as an insulator and piercing a wall of said tank, a block carried on the inner end of said support, a stiff conductor slidably mounted on said support, a clamp slidably mounted in said block and engaging said conductor, an electrode carried on the inner end of said conductor, and means disposed outside the tank for moving said conductor, clamp, and electrode rectilinearly with respect to said support.

22. An ion source for a calutron, which comprises an insulating support, a block carried on one end of said support, a stiff conductor disposed substantially parallel to said support, a clamp slidably mounted in said block and engaging said conductor, an electrode secured to one end of said conductor adjacent said block, and means secured to said support for moving said conductor, clamp, and electrode rectilinearly with respect to said block.

23. An ion source for a calutron, which comprises an elongated insulating support, a block mounted on one end of said support, a stiff conductor mounted in spaced substantially parallel relation to said support, a cathode carried by said conductor and disposed adjacent said block, a clamp block slidably secured to said support and engaging said conductor, and means for moving said conductor and cathode rectilinearly with respect to said support.

24. An ion-producing structure for a calutron having an ionization section and including, means providing an

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electron discharge within the ionization section and producing an ionized vapor, an anode portion of said means mounted adjacent the ionization section in the presence of the ionized vapor, a conductor supporting the anode, an insulating member mounting the conductor upon said structure, an annular shield attached to the structure and surrounding a portion of the member in spaced relation thereto and a second annular shield attached to the conductor and surrounding the remaining portion of the member in spaced relation thereto and to said first shield, whereby vapor is substantially prevented from condensing upon said insulating member.

25. In combination with an apparatus adapted to receive a beam of ions into an evacuated space therein, an exterior wall of said apparatus, a face plate removably attached to said wall, an ion-producing mechanism supported upon said face plate, said mechanism comprising walls defining an ionization chamber with an elongated exit slit providing a passage into the evacuated space from the ionization chamber, means positioned adjacent the extremities of said exit slit for producing electron discharge within said ionization chamber and a plurality of accelerating electrodes mounted upon said face plate and disposed adjacent said exit slit.

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26. An apparatus as described in claim 25 wherein said ion-producing mechanism support includes means providing limited pivotal movement of said mechanism with respect to the face plate upon which said mechanism is supported.

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