

April 14, 1959

E. J. LOFGREN

2,882,408

ION SOURCE FOR A CALUTRON

Filed May 21, 1946

4 Sheets-Sheet 1

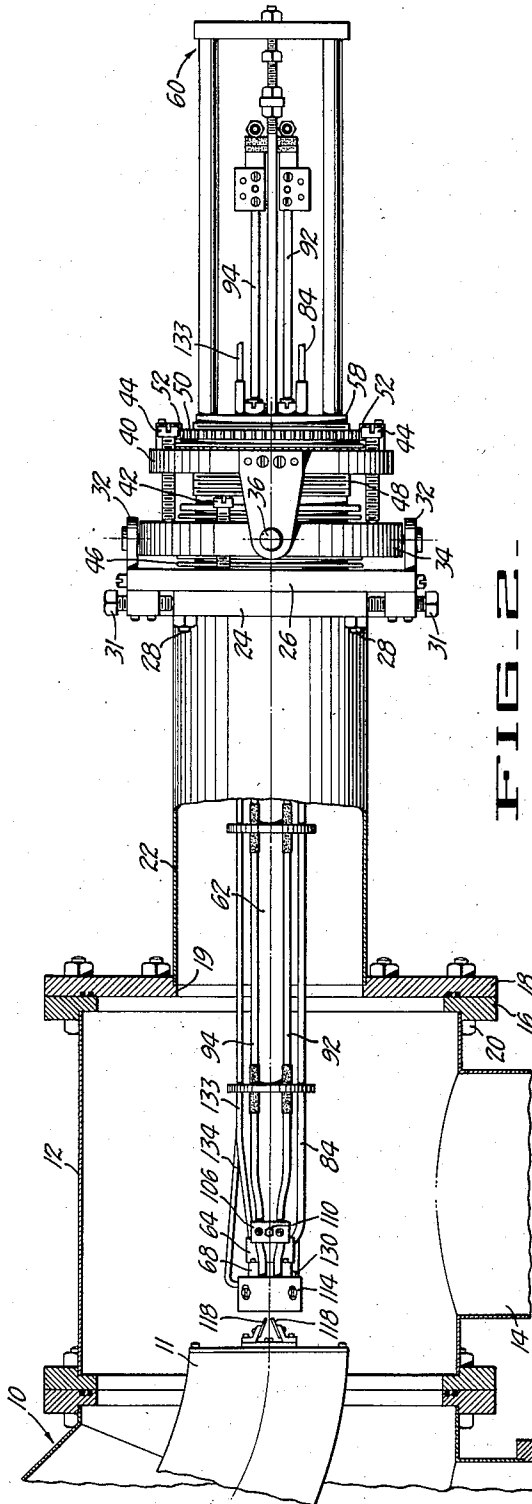


FIG. 2

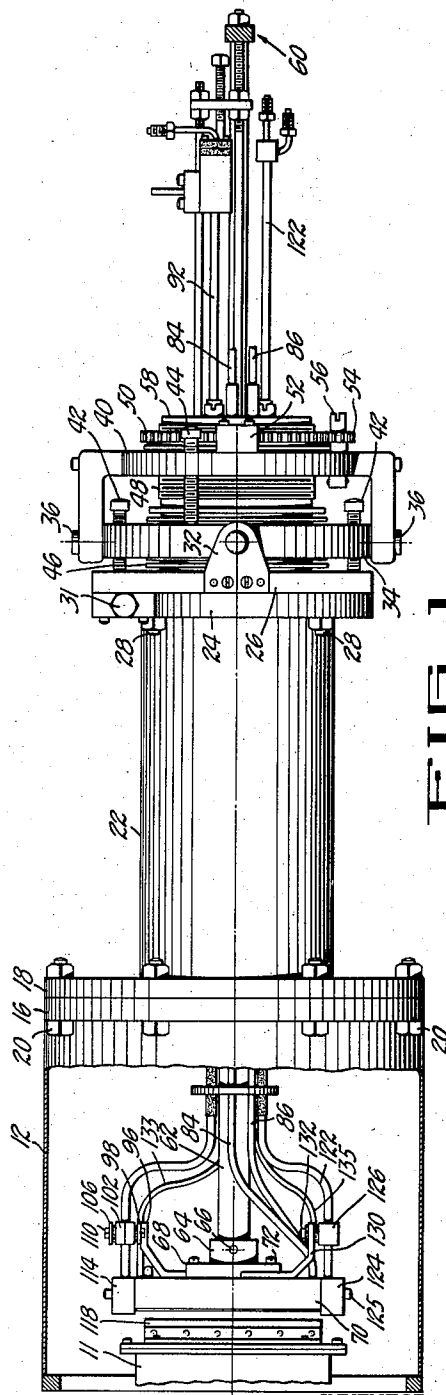


FIG. 1

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4 Sheets-Sheet 2

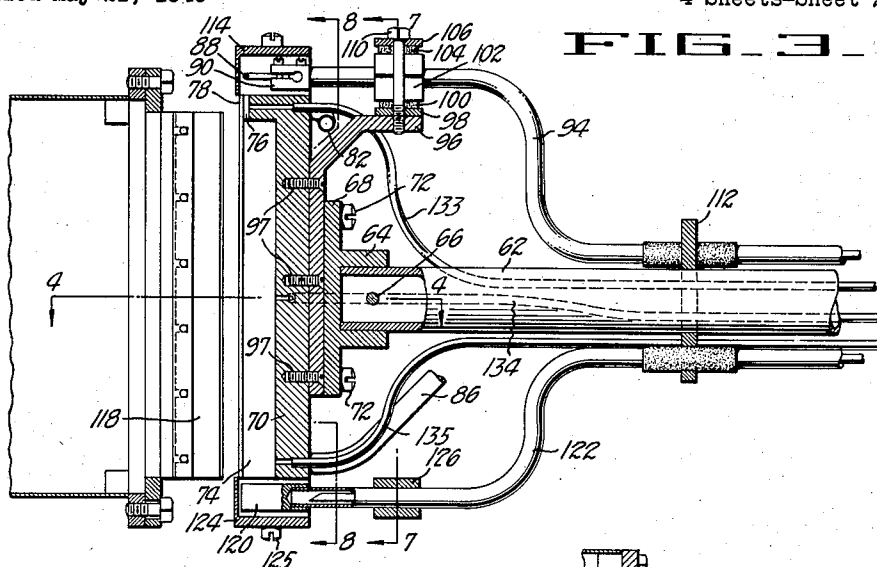


FIG. 3.

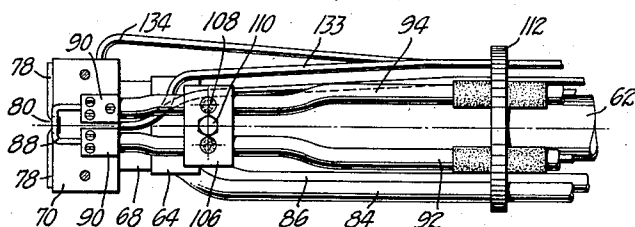


FIG. 5.

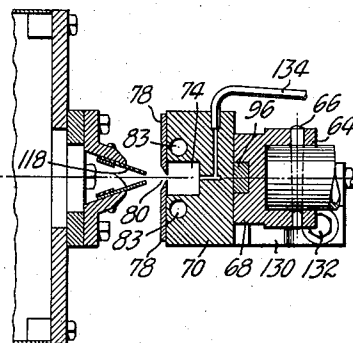


FIG. 4.

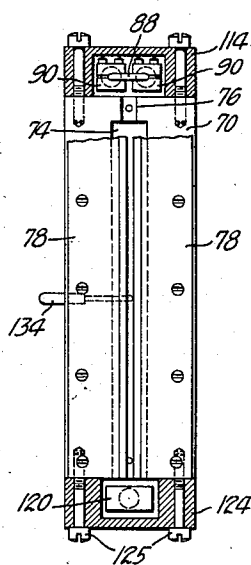
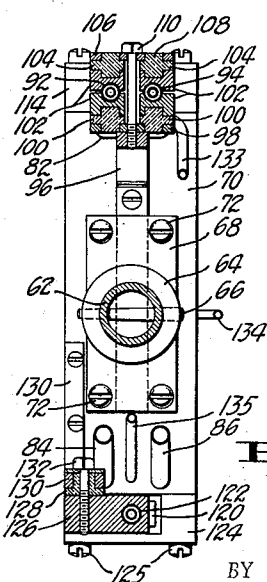


FIG. 6.



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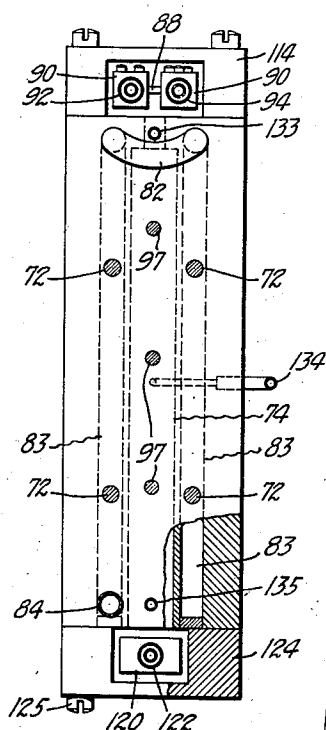


FIG. 8.

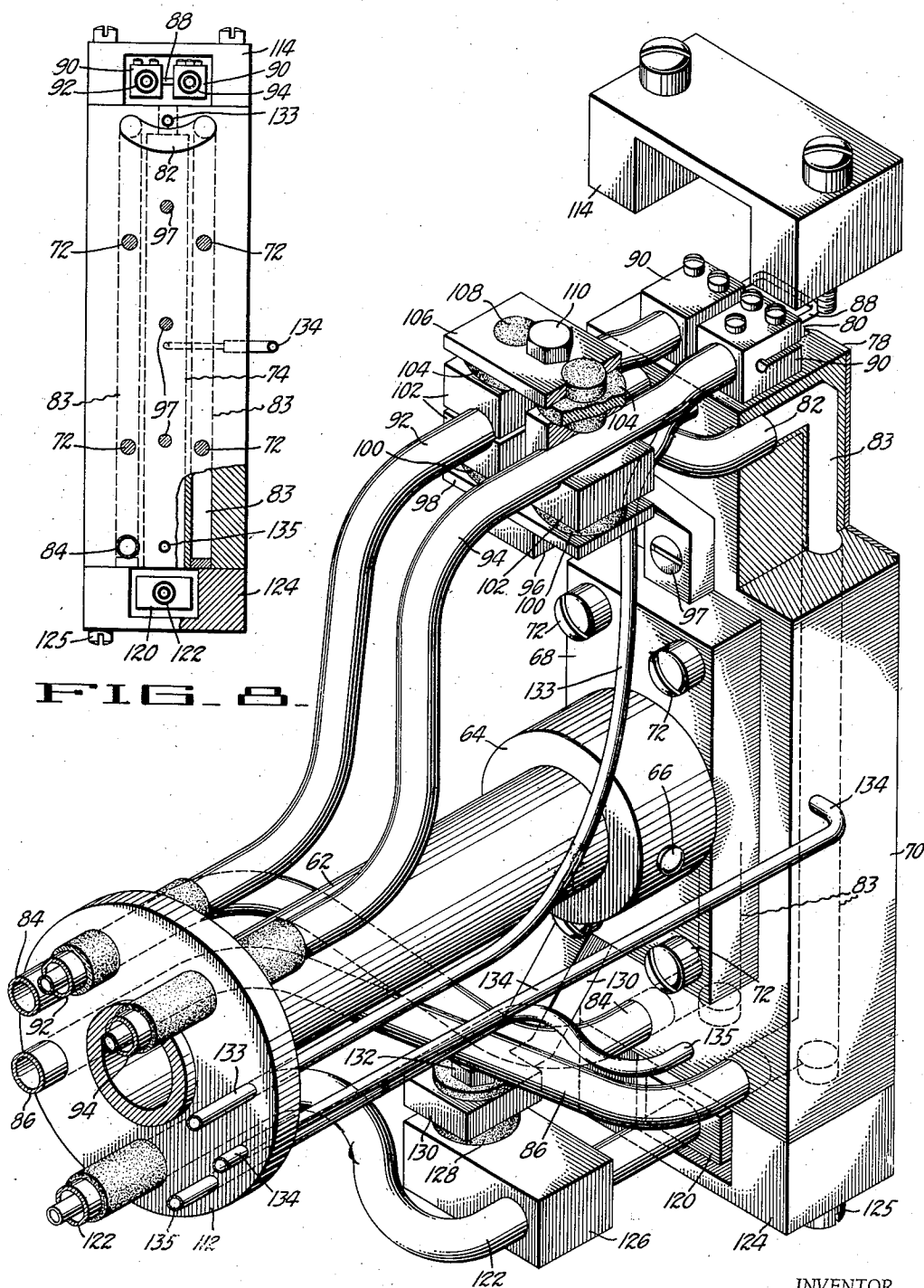


FIG. 9.

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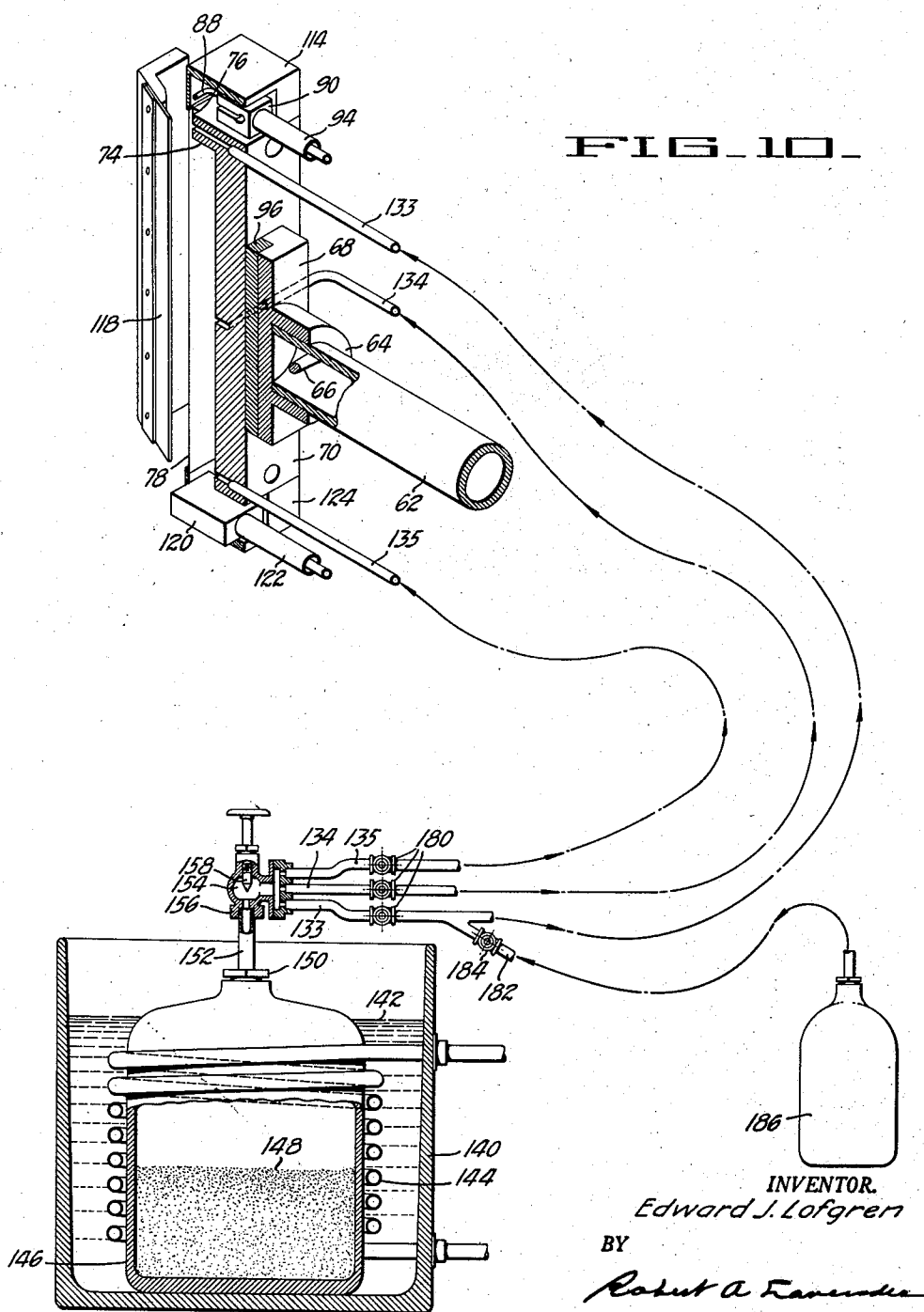
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2,882,408

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2,882,408

## ION SOURCE FOR A CALUTRON

Edward J. Lofgren, Richmond, Calif., assignor to the United States of America as represented by the United States Atomic Energy Commission

Application May 21, 1946, Serial No. 671,197

8 Claims. (Cl. 250—41.9)

The present invention relates to the art of treating a polyisotopic substance to produce a plurality of segregable masses wherein the normal 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 a separating 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 U.S. Patent No. 2,709,222 issued May 24, 1955, to Ernest O. Lawrence. In that patent, the theory of isotopic separation and the principles of operation of a calutron are so fully treated and thoroughly explored that no useful purpose would be served by here repeating the discussion contained therein.

It may be stated, however, that a calutron comprises an evacuated tank disposed between the poles of a powerful magnet and containing means for producing a ribbon or beam of ions of the polyisotopic material undergoing separation. The beam of ions is acted upon by the flux between the pole pieces of the magnet and deflected into a substantially arcuate path wherein ions of heavier isotopes tend to concentrate in the region adjacent the outer periphery and ions of the lighter isotopes congregate in the region adjacent the inner periphery of the curve. In other words, ions of greater mass travel along a curve of greater radius than 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 material in at least two separate masses, of which one is enhanced with respect to one isotope and the other is correspondingly impoverished with respect thereto.

The present invention deals particularly with the mechanism used to produce the beam of ions. Unique problems are presented when it is desired to separate uranium into its constituent isotopes or, more accurately, to produce a mass of uranium in which the percentage of  $U^{235}$  has been substantially increased and the percentage of  $U^{238}$  correspondingly decreased. It has been the custom to utilize  $UCl_4$  as the charge material and to heat a mass of  $UCl_4$  in order to vaporize it. The vapor is then fed through an arc discharge travelling across a chamber provided in one wall with a narrow elongated slit; outside the arc chamber and adjacent the slit is a pair of accelerating electrodes maintained at a highly negative potential with respect to the arc chamber. Consequently positive ions of uranium isotopes formed by the impact of the electrons in the arc upon the molecules of the vaporized  $UCl_4$  are attracted through the slit by the accelerating

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electrodes and pass through the slit at high velocity in the form of a ribbon or beam.

The mechanism heretofore used as a source or ion beam generator has comprised a charge chamber mounted on a stem and supported within the evacuated tank, heaters for heating the charge chamber to vaporize the solid  $UCl_4$  therein, and conduit means leading into an arc chamber fastened to the charge chamber.

It has been found difficult to control the rate at which vapor reaches the arc chamber. It has been found that if insufficient vapor is supplied to the arc chamber, the arc will be feeble and ineffective inasmuch as a certain number of gas molecules are required in the chamber to render the space therein conducting and support the arc discharge. On the other hand, if the supply of vapor to the arc chamber is too great, a condensate will form on the walls of the chamber and silt up the slit, thereby gradually diminishing the efficiency of operation.

An answer to the above-stated problem is an important feature of the invention and comprises using as a charge material  $UF_6$  which at room temperatures has a vapor pressure of about 8 cm. Consequently, it becomes possible to dispose a supply of  $UF_6$  in a container outside the tank, control the rate of vaporization of the charge by controlling the temperature of the chamber, and control the rate of flow of the vapor to the arc chamber by installing a throttle valve in a conduit leading from the charge container to the arc chamber. By this means the arc can be regulated accurately and without an appreciable time lag, inasmuch as the rate of vapor flow is immediately responsive to the manipulation of the throttle valve.

The most important object of the invention, as suggested in the foregoing prefatory remarks, is to provide an ion beam source for a calutron wherein the arc (and thus the beam) is subject to immediately responsive accurate control.

Another object of the invention is to provide an ion beam source for a calutron capable of operating without silting up the slit in the arc chamber and thus to increase the period of time during which the device may be operated without cleaning or recharging.

Another object of the invention is to eliminate wastage by preventing vapor from the charge material from entering the arc chamber until after the tank has been evacuated to operating pressure.

Still another object of the invention is to provide simple and efficient mechanism for producing masses of a material in which the normal distribution of isotopes has been altered.

One feature of the invention consists in the combination of a charge container, an arc chamber, and conduits leading from the charge chamber to a plurality of spaced locations in the arc chamber and provided with independently adjustable valves in order that the vapor may be fed into the arc chamber at any one or combination of selected locations.

Another feature of the invention resides in the use of a charge material which vaporizes at room temperatures, such as  $UF_6$ .

Still another feature of the invention resides in the combination of an arc chamber, a cathode, a relatively long narrow passage connecting the chamber to the region adjacent the filament, and a duct intersecting the passage and connected with a source of vapor or inert gas, whereby the cathode is protected from bombardment by positive ions.

Still another feature of the invention resides in the provision of means whereby the arc may be regulated either by controlling the rate of flow of vapor to the arc chamber or by controlling the rate at which the charge material is vaporized.

Among the advantages incident to the use of an ion beam source embodying the invention are: a flexible arc control, the elimination of vapor waste (resulting from the fact that the supply of vapor to the arc chamber is shut off until the tank has been substantially evacuated), and the fact that apparatus embodying the invention may include a relatively large charge container to substantially increase the period during which a calutron can be operated without recharging.

It should be pointed out that a further advantage incident to the use of apparatus embodying the invention is the fact that the charge container and throttle valve comprise means for maintaining the source compound anhydrous and out of contact with the atmosphere and decomposing or other oxidizing conditions at least until the apparatus is substantially evacuated at the operating temperature, and hence substantially free of air and moisture.

These and other objects and features of the invention together with additional advantages relating thereto will be more readily 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:

Figure 1 is a view in side elevation through a portion of a calutron illustrating an ion beam source embodying the invention;

Fig. 2 is a plan view of the source;

Fig. 3 is a view partially in side elevation and partially in cross section through the transmitting end of the source mechanism;

Fig. 4 is a view in cross section along the line 4—4 of Fig. 3;

Fig. 5 is a plan view of the inner end of the source unit;

Fig. 6 is a view in end elevation with portions broken away to show the arrangement of the anode and the cathode;

Fig. 7 is a view in cross section taken along the line 7—7 of Fig. 3;

Fig. 8 is a view in cross section along the line 8—8 of Fig. 3;

Fig. 9 is a view in perspective of the source unit; and

Fig. 10 is a diagrammatic view partly in cross section showing the arrangement of the charge container and conduits leading to the source unit.

As appears in Figures 1 and 2 a substantially C-shaped tank 10 formed of relatively stout light-gauge metal is disposed between the pole pieces of a powerful magnet (not shown). Within the tank is a hollow, tubular metal liner 11 supported in spaced relation to the walls of the tank and insulated therefrom. At one end of the tank is a terminal section 12 bolted in place and connected to the body of the tank by a vacuum-tight joint. The terminal section 12 is provided with an outlet 14 adapted to be connected to a constantly operating vacuum pumping system (not shown) by means of which the tank may be evacuated and maintained at suitable operating pressure, preferably of the order of  $10^{-5}$  to  $10^{-4}$  mm. Hg. (As used herein the terms "inner" and "outer" relate to the tank and terminal section 12.) The outer end of the terminal section 12 is provided with a rim or flange 16 to which is bolted a mounting plate 18, there being a series of bolts 20 arranged to pass through holes bored in the periphery of the mounting plate 18 and by means of which the flange 16 and the plate 18 are secured together. The mounting plate 18 is centrally apertured as shown at 19, and a stout, cylindrical support tube 22 is welded to the periphery of the aperture 19. At its outer end the tube 22 is welded to a centrally apertured plate 24 of relatively heavy metal. A flat metal plate 26 is secured to the outer face of the plate 24 by means of a plurality of studs 28 fast in the plate 26 and received in oversized holes in the plate 24. By loosening the nuts on the studs 28 the plates 24 and 26 may be rotated

slightly with respect to each other, and the desired condition of adjustment is obtained and preserved by means of a pair of set screws 31 passing through a pair of lugs disposed on the inner surface of the plate 26 and bearing against an upwardly projecting shoulder integral with the plate 24.

The plate 26 also carries a pair of oppositely disposed ears 32 within which are received a pair of pivot pins fast to a gimbal ring 34. Spaced  $90^\circ$  apart from the pivot pins on the ring 34 is a pair of oppositely disposed pivot pins 36 which are received in a pair of ears secured to the periphery of a second gimbal ring 40. That the relative positions of the gimbal rings to each other and to the plate 26 may be fixed, there are provided a first pair of set screws 42 received in holes in the gimbal ring 34 and bearing against the outer surface of the plate 26 and a second pair of set screws 44 received in the gimbal ring 40 and working against the outer surface of the gimbal ring 34. Welded to the outer surface of the plate 26 and encompassing a central aperture therein is an expansible cylindrical bellows of flexible metal secured at its outer end to a tubular metal sleeve 48, the outer surface of which is threaded to engage threads formed in an aperture in a ring gear 50 bearing against the outer surface of the gimbal ring 40 and arranged for rotation with respect thereto. A pair of keepers 52 is secured to the gimbal ring 40 and arranged to embrace the outer surface of the ring gear 50 to prevent its displacement axially from the gimbal ring 40. Also secured to the gimbal ring 40 is a pinion 54 keyed to a stub shaft 56 journaled in the gimbal ring 40. The outer end of the sleeve 48 is secured to a ring 58 within which is received a plug (not shown) supporting a stem 62 which traverses the support tube 22 and extends into the interior of the terminal section 12 of the tank 10. Tensioning mechanism 60 is provided to draw the plug against the ring 58 and to effect a vacuum seal between these two members. More complete details of the gimbal ring mount, the tensioning mechanism, and the operation of the ring gear 50 are to be found in an application for Letters Patent of the United States, Serial No. 582,431, filed March 13, 1945, by Edward J. Lofgren, and issued March 6, 1956, as U.S. Patent No. 2,737,590. It suffices to say here that manipulation of the set screws 31 results in rotating the stem 62 about its axis; manipulation of the set screws 42 is effective to move the stem 62 through a vertical plane; manipulation of the set screws 44 is effective to swing the stem 62 through a horizontal plane, and manipulation of the pinion and ring gear 50 results in translating the stem axially. The bellows 46 conforms to the movements imparted as the result of these adjustments and preserves the vacuum with the tank 10 and the support tube 22.

At its inner end the stem 62 enters a cylindrical socket 64 and is fixed thereto by means of a pin 66 which passes through the walls of the socket and the end of the stem. The socket is integral with a flat supporting plate 68 secured by four screws 72 to an elongated metal block 70 which is hollowed out to form a narrow elongated arc chamber 74, the inner wall of which is cut away and partially covered by a pair of cooperating plates 78 secured to the front end of the block 70 and forming between them a narrow elongated slit 80. At its upper end the chamber 74 is provided with a relatively long collimating passage or bore 76 of small cross-section which leads out through the top of the block 70.

The block 70 is also bored out to form a pair of cooling conduits 83 parallel to the long axis of the arc chamber 74, connected at the upper end of the block by a cross tube 82, and connected at their lower ends to a pair of conduits 84 and 86 leading away from the block 70 and along the stem 62 to the exterior of the tank section 12. A filamentary cathode 88 overlies the upper end of the passage 76 and is secured in a pair of clamping blocks 90 in which terminate a pair of leads 92 and 94 each of

which comprises an outer tube, and an inner tube spaced from the outer tube and terminating within and at the end of the outer tube adjacent the clamping blocks. A cooling fluid may be circulated through each cathode lead. That is to say, a fluid may be fed through the inner tube and back out through the outer tube. A bracket 96 is secured to the block 70 by three screws 97 and is received in a groove formed in the plate 68. At its upper end the bracket 96 is bent rearwardly and flattened to support a plate 98 upon which rests a pair of insulating washers 100. Above each of the washers 100 is a pair of cooperating blocks 102 each of which is grooved to receive a cathode lead; overlying each pair of blocks 102 is an insulating washer 104 in turn surmounted by a plate 106. An insulating pin 108 integral with each washer 104 maintains the alignment of the uppermost of the blocks 102, the washers 104, and the plate 106; and a bolt 110, working through a hole in the plate 106 and received in a hole tapped in the bracket 96, serves to clamp the assembly just described to the bracket 96 and thus to maintain the filamentary cathode 88 in position. The filament leads 92 and 94 and the cooling conduits 84 and 86 pass through a supporting disk 112 disposed on the stem 62. A housing 114 is secured to the top of the block 70 in position to overlie and protect the filament 88 of the terminal clamp locks 90.

Supported on the end of the liner 11 is a pair of angularly disposed accelerating electrode plates 118 disposed a short distance from the end of the block 70 and registering with the slit 80. The bottom of the arc chamber 74 is open, and a block anode 120 carried on the end of a stiff lead 122 is disposed in position to underlie the bottom of the arc chamber 74. A hollow housing 124 is secured to the block 70 by a pair of screws 125 and serves to encompass and protect the anode 120. The lead 122 is of similar construction to the cathode leads 92 and 94. Spaced a short distance rearwardly from the block 70 is a rectangular support member 126 secured to a bracket 130 by a bolt 132, there being insulating washers 128 interposed between the bracket 130, the support block 126, and the head of the bolt 132. The bracket 130 bends upwardly and is secured to the outer face of the block 70.

In order that vapor may be introduced into the arc chamber at spaced locations therein, three conduits are provided. One conduit 133 leads into the block 70 and terminates in one of the walls of the passage 76 beneath the filament 88. A second conduit 134 leads into the side of the block 70 and enters the arc chamber 74 at its mid-point. A third conduit 135 enters the arc chamber just above the anode 120.

The operation of the ion beam source thus far described will be discussed in conjunction with the apparatus shown in Fig. 10 in which the various support members and leads have been eliminated and the arc chamber 74 and the arc block 70 have been shown diagrammatically. Disposed outside of the tank 10 and in any convenient location with respect thereto is a bucket 140 partially filled with water or oil 142 and provided with a coil 144 of copper tubing or other suitable material through which may be circulated refrigerated brine, hot oil, or hot water. Disposed within the turns of the coil 144 is a hermetically sealed charge container or reservoir 146 in which there may be deposited a quantity of charge material such as  $UF_6$ . The container 146 is provided with a cap 150 into which is inserted and sealed a conduit 152 leading to a valve block 156 provided internally with a chamber 154 and providing a support for a needle valve 158 by means of which the flow of gas or vapor from the conduit 152 may be controlled or regulated. The three conduits 133, 134, and 135 are connected to the chamber 154 and each is provided with a valve 180 by means of which the flow of vapor through the conduits may be throttled. The conduit 133 between the arc block 70 and the valve 180 is

connected to a subsidiary conduit 182 controlled by a throttle valve 184 and leading to a gas bottle 186 containing a supply of an inert gas such as helium or argon.

When it is desired to operate the calutron to produce segregable masses of uranium in which the normal distribution of the constituent isotopes has been altered, a supply 148 of  $UF_6$  is placed in the container 146 and the needle valve 158 adjusted completely to close the conduit 152. In passing, it should be stated that  $UF_6$  must be prepared and sealed into the container 146 while anhydrous and out of contact with oxidizing or other decomposing conditions. The pumps are started to evacuate the tank 10 and when the pressure has been reduced to suitable operating conditions, the valve 158 is opened and vapor from the  $UF_6$  flows from the container 146 into the chamber 154 and thence through the conduits 133, 134, and 135 into the arc chamber 74. By manipulation of the valves 180, the vapor may be introduced into the arc chamber in the three locations hitherto described or any combination of them, and the rate of flow of the vapor through the individual conduits may be controlled in each instance by adjustment of the valves 180. When the current is turned on, an arc discharge travels from the filament 88 through the passage 76 to the anode 120 and the stream of electrons therein ionizes the vapor entering the arc chamber. The passage 76 acts to collimate the stream of electrons entering the arc chamber 74. Thus, positive ions of  $U^{234}$ ,  $U^{235}$ , and  $U^{238}$  are formed as well as ions of fluorine. Inasmuch as the accelerating electrodes 118 are carried at a high negative potential with respect to the arc block 70, the positive metal ions are attracted through the slit 80 at high velocity in the form of a narrow beam or ribbon which traverses the tank 10 in an arcuate path.  $180^\circ$  from the slit 80, the metal ions are collected in suitable receivers in at least two separate masses of which one is enriched or enhanced with respect to the percentage of  $U^{235}$  while the other is correspondingly impoverished with respect thereto.

Inasmuch as there is a tendency for positive uranium ions to traverse the collimating passage 76 and impinge upon the cathode 88 to form a relatively weak alloy with the filamentary material, helium or another light inert gas may be fed into the passage 76 through the conduit 133 where it is ionized. The cloud of light helium ions thus formed between the arc chamber and the filament is effective to protect the filament from bombardment by the heavier uranium ions. Consequently, the life of the filament is substantially increased.

The efficiency with which the calutron operates depends to a great extent upon the regulation of the arc, or rather the extent to which the vapor supplied to the arc chamber produces usable ions. Inasmuch as the arc chamber is open to the interior of the tank it is evacuated along with the tank and it is necessary to introduce into the arc chamber a sufficient number of molecules of gas or vapor to render the space in the chamber conducting. On the other hand, if the flow of gas or vapor to the arc chamber is too copious, a relatively large percentage of the vapor molecules will not be ionized and a condensate will form within the chamber and eventually silt up the exit slit. The result, therefore, of an over-supply of vapor to the arc chamber is a decrease in the length of the time the calutron can be operated without cleaning, as well as the fact that the percentage of vapor ionized is reduced. Apparatus embodying the invention is advantageous for the reason that the supply of vapor to the arc chamber may be accurately and easily controlled. In other words, it is possible to supply to the arc chamber vapor in sufficient quantity not only to support an arc but also to produce the maximum ionization. Furthermore, by manipulating the valves 180 it is possible to introduce more vapor at one location in the chamber than at others. For example, it is believed advantageous to supply more

vapor to the region adjacent the anode than should be supplied to the center of the chamber or to the region adjacent the upper end of the chamber near the cathode.

By regulating the temperature of the charge container 146 the rate of vaporization of the charge material can be controlled. In the case of  $UF_6$  it has been found desirable to reduce the temperature of the container 146, since  $UF_6$  at room temperature exhibits a vapor pressure of about 80 millimeters which produces too copious a supply of vapor through the arc chamber. Necessarily, the control of the rate of flow by this means is somewhat slow and not satisfactorily precise. Consequently, the throttle valve 158 performs a highly desirable function, since it provides means whereby the flow of vapor to the arc chamber may be controlled precisely, accurately, and rapidly. That is to say, the rate of flow of vapor through the conduit is immediately responsive to the manipulation of the throttle valve 158. Furthermore, the vacuum in the tank would draw vapor from the container at too fast a rate were it not for the throttling function of the valve 158.

It should be understood that while the apparatus above described represents the best mode now known for embodying the invention, many changes and variations will be evident to those skilled in the art and the scope of the invention is not limited to the specific embodiments shown herein but should be measured by the appended claims.

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

1. A calutron comprising an evacuated tank, a block supported within said tank and having a chamber, a cathode disposed adjacent one end of said chamber, an anode disposed adjacent the opposite end of said chamber, a container for a charge of vaporizable material disposed outside said tank, means for varying the temperature of said container, a plurality of conduits connected to said container and communicating with said chamber at the ends thereof as well as at intermediate locations therebetween, means for controlling the rate of flow of fluid from said container to said chamber, means including a plurality of throttle valves for selectively opening or closing each of said conduits, a source of inert gas, and means for introducing inert gas from said source into one of said conduits.

2. A calutron comprising a block having an elongated chamber and a passage leading from one end of said chamber to the exterior of said block, a cathode disposed adjacent the outer end of said passage, a container for a charge of vaporizable material, a plurality of conduits connected to said container and communicating with said chamber, and a conduit connected to said container and communicating with said passage.

3. A calutron comprising a block having an elongated chamber and a bore leading from one end of said chamber to the exterior of the block, a cathode disposed adjacent the outer end of said passage, a container for a charge of vaporizable material, a plurality of conduits connected to said container and communicating with said chamber at spaced points therein, a source of inert gas, and a conduit connected to said source and communicating with said passage.

4. A calutron comprising a vacuum envelope, an arc ion source within said envelope, said ion source including a filament chamber and an arc chamber connected by a collimating passage, and conduit means for conducting ionizable gas into said ion source, one of said conduits intersecting said collimating passage.

5. A calutron comprising a vacuum envelope, an ion source within said envelope, said ion source including an elongated arc chamber, a plurality of means for admitting ionizable gas to said arc chamber at a plurality of locations spaced along the length thereof, a reservoir of ionizable gas, and means for connecting said reservoir to any selected one of said plurality of admitting means.

6. An ionizing device comprising an evacuated vessel, a block disposed within said vessel and having a chamber, an electron-emissive filament disposed adjacent one end of said chamber, a container for gas, a plurality of conduits connecting said container to a plurality of spaced outlets in said chamber, one of said outlets being adjacent said filament end and another outlet adjacent the other end of said chamber, means for establishing an arc discharge from said filament within said chamber, and means for controlling the rate of flow of gas from said container to said chamber, whereby the arc may be regulated by varying the amount of gas introduced into said chamber.

7. A calutron which comprises an evacuated vessel, a chambered block disposed within said vessel, means for introducing an ionizable gas into said chamber at a plurality of spaced locations one of which is adjacent one end and another adjacent the opposite end of said chamber, means for establishing an arc within said chamber between the aforementioned ends, and valve means for regulating the introduction of gas into said chamber to control the arc.

8. A calutron comprising a block having a chamber, a container for vaporizable material, heat exchange apparatus associated with said container, a plurality of conduits connecting said container to said chamber at a plurality of locations, one of said locations being adjacent one end of said chamber and another adjacent the opposite end, means for selectively closing and opening each of said conduits, and means for establishing an arc through said chamber between the aforementioned ends thereof.

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