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C. STARR

2,813,979

APPARATUS FOR PRODUCING IONS OF VAPORIZABLE MATERIALS

Filed Sept. 25, 1944

2 Sheets-Sheet 1

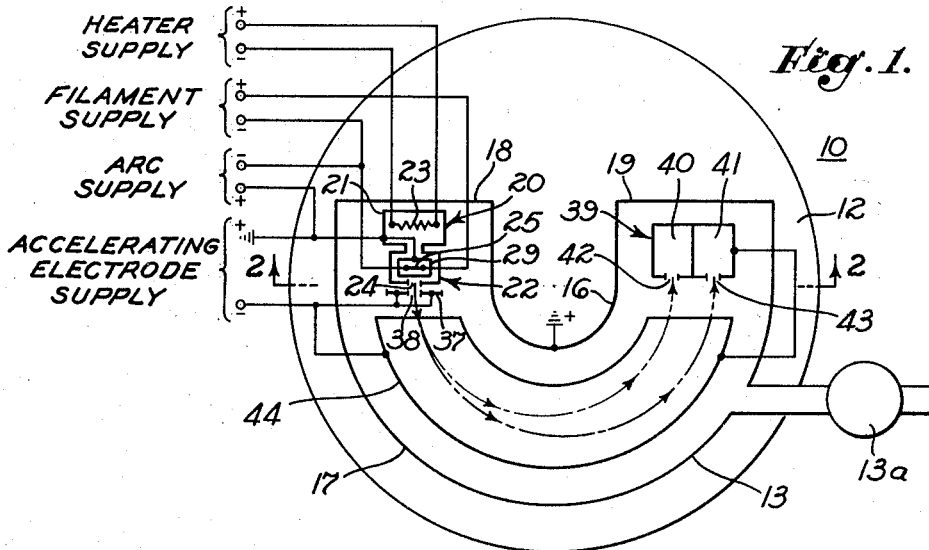


Fig. 2.

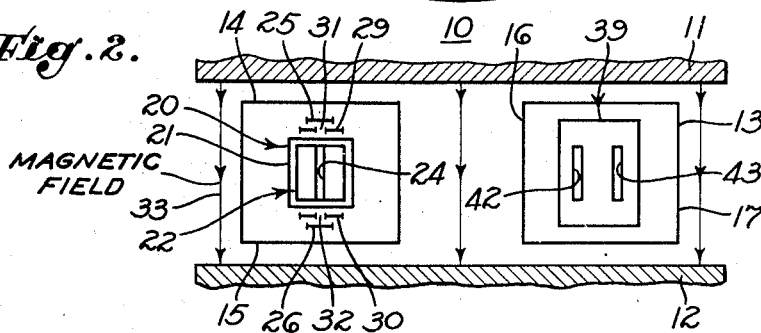
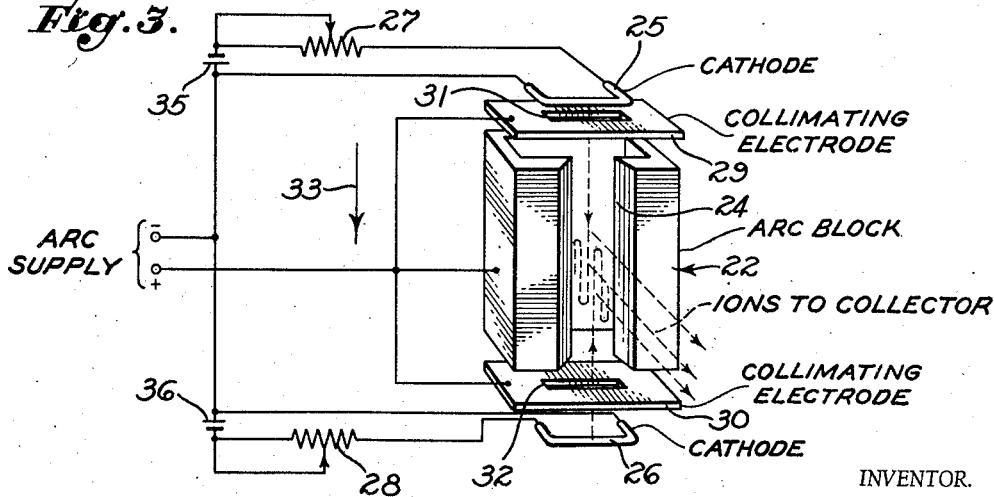


Fig. 3.



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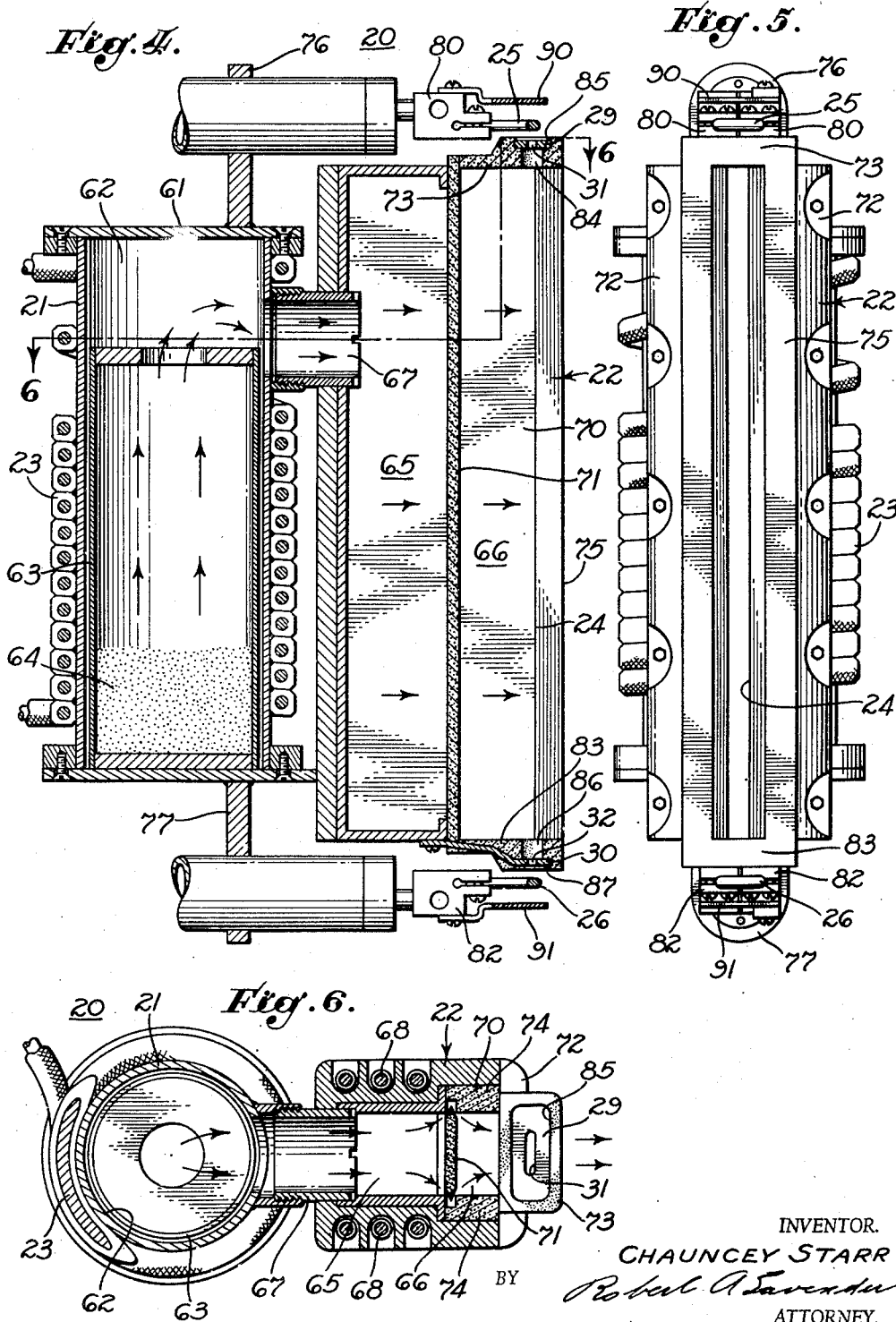
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2 Sheets-Sheet 2



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APPARATUS FOR PRODUCING IONS OF VAPORIZABLE MATERIALS

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9 Claims. (Cl. 250—41.9)

The present invention relates to electric discharge devices and more particularly to calutron ion sources.

It is an object of the invention to provide an improved ion source having a gaseous region with two sources of gas ionizing electrons respectively disposed on opposite sides thereof for directing such electrons into the region, thereby producing a substantially uniform arc discharge along its length in the region.

Another object is to provide an improved ion source having a gaseous region with a pair of cathodes respectively disposed on opposite sides thereof and means for projecting electrons emitted from the cathodes into the gaseous region to produce an arc of substantially uniform intensity and cross section throughout its length.

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

The invention, both as to its organization and method of operation, together with other objects and advantages thereof, will best be understood by reference to the following specification taken in connection with the accompanying drawings, in which Figure 1 is a diagrammatic plan view of a calutron incorporating an ion source unit embodying the present invention; Fig. 2 is a diagrammatic sectional elevational view of the calutron taken along the line 2—2 in Fig. 1; Fig. 3 is a schematic perspective view of the electrode arc block arrangement incorporated in the ion source unit of the calutron; Fig. 4 is a longitudinal sectional view of the calutron ion source unit, illustrating the structure thereof; Fig. 5 is a front elevational view of the ion source unit shown in Fig. 4; and Fig. 6 is a sectional view of the ion source unit, taken along the line 6—6 in Fig. 4.

At the outset, it is noted that a "calutron" is a machine of the character of that disclosed in the copending application of Ernest O. Lawrence, Serial No. 557,784, filed October 9, 1944, and is employed to separate the constituent isotopes of an element and, more particularly, to increase the proportion of a selected isotope in an element containing several isotopes in order to produce the element enriched with the selected isotope. For example, the machine is especially useful in producing uranium enriched with U²³⁵.

Such 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

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thus concentrated, thereby to produce a deposit of the element enriched with the selected isotope.

In accordance with the present invention, an improved ion source is provided in which electrons are projected into the vapor containing region from opposite sides thereof, whereby the electrons encounter and ionize molecules of the vapor. Preferably, the electrons are projected into the region from two electron sources disposed at opposite ends thereof, each electron source comprising a cathode and an apertured electrode, the two cathodes and the openings in the apertured electrodes being disposed with the long dimensions thereof parallel to each other across a magnetic field extending through the region and having dimensions proportioned to define a single arc discharge along a line between the two electron sources. With such an electrode arrangement, an arc discharge of uniform cross section and of increased uniformity in ion production efficiency throughout its length may be produced in the vapor containing region. When such an ion source is used in a calutron, an arc discharge of increased length may be utilized, thereby increasing the efficiency and economy of commercial calutron operation.

Referring now more particularly to Figs. 1 and 2 of the drawings, there is illustrated a calutron provided with an ion source unit embodying the features of the present invention. The calutron 10 comprises magnetic field structure including upper and lower pole pieces 11 and 12, provided with substantially flat parallel spaced-apart pole faces, and a tank 13 disposed between the pole faces of the pole pieces 11 and 12. The pole pieces 11 and 12 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 13 and the various parts housed therein. The tank 13 is of tubular configuration, being substantially U- or crescent-shaped in plan, and comprising substantially flat parallel spaced-apart top and bottom walls 14 and 15, upstanding curved inner and outer side walls 16 and 17, and end walls 18 and 19. The end walls 18 and 19 close the ends of the tubular tank 13 and are adapted to be removably secured in place, whereby the tank 13 is hermetically sealed. Also, vacuum pumping apparatus 13a is associated with the tank 13, whereby the interior of the tank 13 may be evacuated to a pressure of the order of 10⁻⁵ to 10⁻⁴ mm. Hg. Preferably, the component parts of the tank 13 are formed of steel, the top and bottom walls 14 and 15 thereof being spaced a short distance from the pole faces of the upper and lower pole pieces 11 and 12, respectively, the tank 13 being retained in such position in any suitable manner, whereby the top and bottom walls 14 and 15 constitute in effect pole pieces with respect to the interior of the tank 13, as explained more fully hereinafter.

The removable end wall 18 suitably supports an ion source unit 20 comprising a charge receptacle 21 and a communicating arc-block 22. An electric heater 23 is arranged in heat exchange relation with the charge receptacle 21 and is adapted to be connected to a suitable source of heater current supply, whereby the charge receptacle 21 may be appropriately heated, the charge receptacle 21 being formed of steel or the like. The arc-block 22 is formed, at least partially, of carbon or graphite and is substantially C-shaped in plan, a slot 24 being formed in the wall thereof remote from the charge receptacle 21. Thus, the arc-block 22 is of hollow construction, the cavity therein communicating with the interior of the charge receptacle 21.

Also, the removable end wall 18 carries a pair of filamentary cathodes 25 and 26 adapted to be connected to suitable sources of filament supply, the filamentary cathodes 25 and 26 being respectively disposed at the

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upper and lower ends of the arc-block 22 and arranged in alignment with respect to the ends of the cavity formed therein. Further, the removable end wall 18 carries a pair of collimating electrodes 29 and 30 respectively disposed at the upper and lower ends of said arc-block 22 and also arranged in alignment with respect to the ends of the cavity formed therein. The respective collimating electrodes 29 and 30 have collimating slots 31 and 32 therethrough, the collimating slots 31 and 32 being aligned with the filamentary cathodes 25 and 26 and the magnetic field 33. The collimating electrodes 29 and 30 are electrically connected to the arc-block 22 and to the charge receptacle 21, which in turn are grounded; likewise the tank 13 is grounded. Also, the filamentary cathodes 25 and 26 and the arc-block 22 are adapted to be connected to a suitable source of arc current supply.

Further, the removable end wall 18 carries an accelerating structure 37 formed of carbon or graphite, and disposed in spaced-apart relation with respect to the wall of the arc-block 22 in which the slot 24 is formed. More specifically, a slit 38 is formed in the ion accelerating structure 37 and arranged in substantial alignment with respect to the slot 24 formed in the wall of the arc-block 22. A suitable source of accelerating electrode potential is adapted to be connected between the arc-block 22 and the ion accelerating structure 37, the positive and negative terminals of this supply being respectively connected to the arc-block 22 and to the ion accelerating structure 37. Further, the positive terminal of the ion accelerating electrode potential source is grounded.

The removable end wall 19 suitably supports a collector block 39 formed of stainless steel or the like and provided with two laterally spaced-apart cavities or pockets 40 and 41 which respectively communicate with aligned slots 42 and 43 formed in the wall of the collector block 39 disposed remote from the removable end wall 19. It is noted that the pockets 40 and 41 are adapted to receive two constituent isotopes of an element which have been separated in the calutron 10, as explained more fully hereinafter. Further, the inner wall 16 suitably supports a tubular liner 44 formed of copper or the like, rectangular in vertical cross section, disposed within the tank 13 and spaced from the walls 14, 15, 16, and 17. One end of the tubular liner 44 terminates adjacent the accelerating structure 37; and the other end of the tubular liner 44 terminates adjacent the collector block 39; the tubular liner 44 constituting an electrostatic shield for the high velocity ions traversing the curved paths between the slit 38 formed in the ion accelerating structure 37 and the slots 42 and 43 formed in the collector block 39, as explained more fully hereinafter. Finally, the tubular liner 44 is electrically connected to the ion accelerating structure 37 and to the collector block 39. Thus, it will be understood that the ion source unit 20 and the tank 13 are connected to the grounded positive terminal of the accelerating electrode potential supply; while the ion accelerating structure 37, the tubular liner 44, and the collector block 39 are connected to the ungrounded negative terminal of the accelerating electrode supply; the ion accelerating structure 37, the tubular liner 44, and the collector block 39 being electrically insulated from the component parts of the tank 13.

Referring now more particularly to Fig. 3 of the drawing, the electrode arrangement of the arc-block 22 of the calutron ion source unit 20 embodying the features of the present invention is illustrated schematically in perspective. More particularly, this electrode arrangement comprises, among other elements, a pair of substantially U-shaped filamentary cathodes 25 and 26 formed of tungsten, tantalum, or the like, a pair of plate-like collimating electrodes 29 and 30 formed of

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tungsten, molybdenum or the like, and the elongated arc-block 22. The electrodes mentioned are arranged in the magnetic field of the calutron, the direction of the field between the north pole and the south pole of the field structure being indicated by the arrow 33. The filamentary cathodes 25 and 26 are arranged in substantially parallel spaced-apart relation across the magnetic field mentioned; while the collimating electrodes 29 and 30 are arranged between the filamentary cathodes 25 and 26 at opposite ends of the arc-block 22 in substantially parallel relation with the filamentary cathodes 25 and 26 and also across the magnetic field mentioned. The collimating electrodes 29 and 30 have elongated, transversely extending collimating slots 31 and 32 formed therethrough and disposed in alignment with the central portions of the U-shaped filamentary cathodes 25 and 26, the collimating electrode 29 being disposed closely adjacent the filamentary cathode 25, and the collimating electrode 30 being disposed closely adjacent the filamentary cathode 26. Accordingly, the filamentary cathodes 25 and 26 and the collimating electrodes 29 and 30 are respectively disposed in four substantially parallel spaced-apart planes disposed substantially normal to the magnetic field mentioned. Furthermore, the central portions of the filamentary cathodes 25 and 26 and the central portions of the slots 31 and 32 formed in the collimating electrodes 29 and 30 are arranged in alignment with the magnetic field mentioned.

The widths of the slots 31 and 32 formed in the collimating electrodes 29 and 30 are less than the corresponding widths of the central portions of the filamentary cathodes 25 and 26 and the lengths of the slots 31 and 32 are shorter in the transverse direction than the lengths of the central portion of the filamentary cathodes 25 and 26, whereby the dimensions of the slots 31 and 32 formed in the collimating electrodes 29 and 30 are less than the corresponding dimensions of the filamentary cathodes 25 and 26 disposed adjacent thereto. Preferably, the two filamentary cathodes 25 and 26 are of the same dimensions and the two collimating electrodes 29 and 30 and the respective collimating slots 31 and 32 therein are also of the same dimensions. Thus an ion source is provided having a pair of electron sources symmetrically disposed on opposite sides of a region containing vapor to be ionized, the electron sources being arranged to project electrons into the region from the opposite sides thereof.

The filamentary cathodes 25 and 26 are electrically connected by way of adjustable resistors 27 and 28 to corresponding sources of filament current supply indicated as batteries 35 and 36; the filamentary cathodes 25 and 26 are connected to the negative terminal of the arc current supply; and the arc-block is connected to the positive terminal of the arc current supply. The collimating electrodes 29 and 30 are electrically connected to the arc-block 22, whereby a substantially electric-field-free zone is defined therebetween in the gaseous region in the arc-block.

Considering now the general principle of operation of the calutron 10 shown in Figs. 1 and 2 incorporating the ion source unit illustrated, a charge comprising a compound of the element to be treated is placed in the charge receptacle 21, the compound of the element mentioned being one which may be readily vaporized. The end walls 18 and 19 are securely attached to the open ends of the tank 13, whereby the tank 13 is hermetically sealed. The various electrical connections are completed and operation of the vacuum pumping apparatus 13a associated with the tank 13 is initiated. When a pressure of the order of 10^{-5} to 10^{-4} mm. Hg. is established within the tank 13, the electric circuits for the windings, not shown, associated with the pole pieces 11 and 12 are closed and adjusted, whereby a predetermined magnetic field is established therebetween traversing the tank 13. The electric circuit for the heater 23 is closed, whereby the charge in the charge receptacle 21 is heated and vaporized. The vapor fills the charge receptacle 21 and is conducted into the

communicating cavity formed in the arc-block 22. The electric circuits for the filamentary cathodes 25 and 26 are closed, whereby the filamentary cathodes are heated and rendered electron emissive. Then the electric circuit between the arc current supply source, the filamentary cathodes 25 and 26 and the arc-block 22 is closed, rendering the filamentary cathodes 25 and 26 negative with respect to the collimating electrodes 29 and 30 and the arc-block 22. Accordingly, electrons are projected from the filamentary cathodes 25 and 26 toward the corresponding collimating electrodes 29 and 30 along the magnetic field 33. Some of these electrons pass through the slots 31 and 32 formed in the collimating electrodes 29 and 30 and continue into the cavity of the arc-block, whereby the gas or vapor in the zone between the collimating electrodes 29 and 30 in the gaseous or vapor region is ionized. The electrons proceeding from the filamentary cathodes 25 and 26 through the collimating slots 31 and 32 in the collimating electrodes 29 and 30 encounter molecules of the vapor in the cavity of the arc-block 22 and break up the molecular form of the compound forming the vapor to a considerable extent, producing positive ions of the element that is to be enriched with the selected one of its isotopes.

More specifically, the electrons projected from the filamentary cathodes 25 and 26 gain substantially all of their energy in traversing the electric field between the filamentary cathodes 25 and 26 and the corresponding collimating electrodes 29 and 30, and those entering the gaseous or vapor region do so at velocities higher than that required for ionization. Moreover, the electrons traveling into the vapor region through the collimating slots are, for the most part, confined to paths along the magnetic field, inasmuch as any horizontal motion imparted to these electrons will result in their traveling along helices of extremely small radii, the axes of the helices being along the magnetic field.

In view of the fact that the dimensions of the slots 31 and 32 formed in the collimating electrodes 29 and 30 are less than the corresponding dimensions of the filamentary cathodes 25 and 26, the cross section of the electron streams entering the gaseous region disposed between the collimating electrodes 29 and 30 is positively defined and only electrons from the uniform electron emissive surface of the central portions of the filamentary cathodes 25 and 26 are employed. These uniform and steady streams of electrons projected into the gas or vapor region mentioned result in a discharge therethrough along the magnetic field and opposite the slot 24 in the wall of the arc-block 22, whereby a uniform and copious supply of positive ions is produced. This discharge through this region is of the arc type, being characterized by a high current, a low voltage drop, and a luminous plasma. More specifically, most of the electrons projected from the filamentary cathodes 25 and 26 through the slots 31 and 32 in the collimating electrodes 29 and 30 oscillate up and down in the vapor region and gradually drift to the wall of the arc-block where they discharge, thereby completing a circuit between the positive and negative terminals of the arc supply, the current in the arc discharge flowing from the arc-block 22 to the filamentary cathodes, the arc-block 22 thus serving as an anode. It should be noted that the zone disposed between the collimating electrode and the anode is believed to be substantially electric-field-free, the electric field in this zone, both longitudinally and transversely, being of the order of only a few volts and being more positive in the central portion than at the upper and lower ends or the boundary thereof, thus accounting for the longitudinal oscillation of the electrons in the vapor region.

Due to the construction and arrangement of the electrodes of the ion source, the streams of electrons proceeding from the filamentary cathodes 25 and 26 through the slots 31 and 32 formed in the collimating electrodes 29 and 30 form a single ribbon-like configuration, within the boundary of which most of the positive ions formed

in the gas or vapor region are concentrated. This arrangement positively insures a uniform and copious supply of positive ions presenting a well-defined surface to the slot in the wall of the arc-block with which the ion accelerating structure is operatively associated.

The electric circuit between the arc-block 22 and the ion accelerating structure 37 is closed after the ion source unit is in relatively stable operation, the ion accelerating structure 37 being at a high negative potential with respect to the arc-block 22 so that the positive ions in the arc-block 22 are attracted by the ion accelerating structure 37 and accelerated through the voltage impressed therebetween. More particularly, the positive ions proceed from the cavity formed in the arc-block 22 through the slot 24 formed in the wall thereof, and across the space between the ion accelerating structure 37 and the adjacent wall of the arc-block 22, and thence through the slit 38 formed in the ion accelerating structure 37 into the interior of the open ended tubular liner 44. The high-velocity positive ions form a vertical upstanding ribbon or beam proceeding from the cavity formed in the arc-block 22 through the slot 24 and the aligned slit 38 into the tubular liner 44.

As previously noted, the collector block 39, as well as the tubular liner 44, are electrically connected to the ion accelerating structure 37, whereby there is an electric-field-free path for the high-velocity positive ions disposed between the ion accelerating structure 37 and the collector block 39 within the tubular liner 44. The high-velocity positive ions entering the end of the liner 44 adjacent the ion accelerating electrode are deflected from their normal straight-line path and from a vertical plane passing through the center of the slot 24 and the center of the aligned slit 38, due to the effect of the relatively strong magnetic field maintained through the space within the tank 13 and the liner 44 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 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 42 into the pocket 40 formed in the collector block 39; whereas ions of a relatively heavy isotope of the element describe an exterior arc of relatively long radius and are focused through the slot 43 into the pocket 41 formed in the collector block 39. Accordingly, the relatively light ions are collected in the pocket 40 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 41 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 21 has been vaporized, all of the electric circuits are interrupted and the end wall 18 is removed so that another charge may be placed in the charge receptacle 21 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 40 and 41 of the collector block 39, the end wall 19 may be removed and the deposits of the collected isotopes in the pockets 40 and 41 in the collector block 39 may be reclaimed.

Of course, it will be understood that the various dimensions of the parts of the calutron 10, the various electrical potentials applied between the various electrical parts thereof, as well as the strength of the magnetic field between the pole pieces 11 and 12, are suitably correlated with respect to each other, depending upon the mass numbers of the isotopes of the element that is to be treated therein. In this connection, reference is again made to the copending application of Ernest O. Lawrence, for a complete specification of a calutron especially designed for the production of uranium enriched with the

isotope U^{235} . By way of illustration, it is noted that when the calutron 10 is employed in order to produce uranium enriched with U^{235} , the compound of uranium which is suggested as a suitable charge in the charge receptacle 21 is UCl_4 , as this compound may be readily vaporized and the molecular form of the vapor may be readily broken up to form positive ions of uranium with great facility. In this case, uranium enriched with U^{235} is collected in the pocket 40 of the collector block 39, and uranium comprising principally U^{238} is collected in the pocket 41 of the collector block 39. Also, it is noted that from a practical standpoint, the deposit of uranium collected in the pocket 40 of the collector block 39 contains considerable amounts of U^{238} , in view of the fact that this isotope comprises the dominant constituent of normal uranium. Furthermore, the deposit of uranium collected in the pocket 40 of the collector block 39 contains a considerably increased amount of U^{234} , in view of the fact that it is not ordinarily feasible to separate U^{234} and U^{235} in the production of relatively large quantities of uranium enriched with U^{235} for commercial purposes. Accordingly, in this arrangement the uranium deposited in the pocket 40 of the collector block 39 is considerably impoverished with respect to U^{238} as compared to natural or normal uranium.

In the operation of the calutron 10, it is highly desirable that a relatively intense stable beam of positive ions be projected by the ion accelerating structure 37, through the liner 44, toward the collector block 39; which operating condition requires that the source unit 20 be productive of a steady and copious supply of positive ions. To accomplish this end in the source unit 20, the arc discharge within the cavity in the arc-block 22 should be both relatively intense and uniform. Moreover, it is desirable that such an arc discharge should be steady and free from both intensity and position variations in order that the ion source unit 20 be productive of a highly continuous, copious and uniform supply of positive ions. Furthermore, the ion source unit 20 should be so constructed and arranged that the parts thereof are subjected to minimum wear and erosion, whereby the unit has a long life and an efficient operating characteristic. An improved ion source unit embodying the features of the present invention provides an arc discharge of greater uniformity throughout the length of the arc.

Referring now more particularly to Figs. 4 to 6, inclusive, of the drawings, there are illustrated the structural details of the calutron ion source unit which is arranged in the magnetic field between the pole pieces of the calutron 10 in the manner previously explained, the ion source unit 20 comprising a charge receptacle 21 and an arc-block 22. The charge receptacle 21 comprises wall structure, including a removable cover 61, defining an upstanding cylindrical cavity 62 therein, that is adapted to receive a removable cylindrical charge bottle 63 containing a charge 64 which is to be vaporized. The arc-block 22 comprises wall structure defining an upstanding vapor distributing chamber 65 and an upstanding arc chamber 66, the cavity 62 communicating with the vapor distributing chamber 65 through a tubular member 67 supported by the wall structure of the charge receptacle 21 and the wall structure of the arc-block 22. The wall structure of the charge receptacle 21 carries an exteriorly arranged electric heater 23 of any suitable form, whereby the charge receptacle 21 and the charge bottle 63 may be appropriately heated in order to vaporize the charge 64 contained in the charge bottle 63. Similarly, the wall structure of the arc-block 22 carries an exteriorly arranged electric heater 68 of any suitable form, as shown in Fig. 6, whereby the arc-block 22, and more particularly the vapor distributing chamber 65 therein, may be heated in order to prevent condensation of the contained vapor, as explained more fully hereinafter.

A rectangular-shaped frame member 70, formed of carbon or graphite, is held between the side walls of the

main wall structure of the arc-block 22 by two upstanding strips 72 attached to the arc-block with suitable screws. The frame member 70 comprises a top wall 73, a bottom wall 83, two upstanding substantially parallel spaced-apart side walls 74, and a front wall 75, the front wall 75 having a centrally disposed longitudinal slot 24 formed therein and communicating with the arc chamber 66. The side edges of the baffle plate 71 are spaced a short distance from the side walls 74 of the frame member 70 in order to provide communicating channels between the vapor distributing chamber 65 and the arc chamber 66 along the vertical beveled edges of the baffle plate 71, said baffle defining the boundary between the chambers mentioned.

The wall structure of the charge receptacle carries standards 76 and 77 which support cathode structure in cooperating relationship with respect to the arc-block 22, the cathode structure comprising two similar elements symmetrically located at opposite ends and exterior to the frame member 70. More particularly, one of the cathode structures comprises two terminals 80 supporting the opposite ends of the substantially U-shaped filamentary cathode 25 above the transverse wall 73 at the upper end of the frame member 70, and two terminals 82 supporting the opposite ends of the substantially U-shaped filamentary cathode 26 beneath the transverse wall 83 at the lower end of the frame member 70. The opposite ends of the filamentary cathodes 25 and 26 are removably clamped in place by the respective terminals 80 and 82, and these two terminals 80 and the two terminals 82 are connected to a suitable source of filament supply, as previously noted. The central portion of the filamentary cathode 25 is positioned above the central portion of the top wall 73 of the frame member 70, the top wall 73 having a transversely extending slot 84 formed therethrough communicating with the arc chamber 66. The upper end of the transverse slot 84 is provided with a counter recess 85 extending thereabout which receives the collimating electrode 29. The collimating electrode 29 has the transversely extending slot 31 formed therethrough, as previously noted, communicating with the transverse slot 84 formed in the top wall 73 and consequently with the arc chamber 66, the length of the slot 31 being greater than the width of the slot 24 formed in the front wall 75. The central portion of the filamentary cathode 26 is positioned beneath the central portion of the bottom wall 83 of the frame member 70, the bottom wall 83 having a transversely extending slot 86 formed therethrough communicating with the arc chamber 66. The collimating electrode 30 is attached to the bottom wall of the chamber 65 by suitable screws and supports the bottom of the baffle 71 as well as the frame 70; said collimating electrode 30 is provided with a transversely extending slot 32 formed therethrough, communicating with the transverse slot 86 formed in the bottom wall 83 and consequently with the arc chamber 66, the length of the slot 32 likewise being greater than the width of the slot 24 formed in the front wall 75. More particularly, the filamentary cathode 25 is spaced a short distance above the collimating electrode 29, and the filamentary cathode 26 is spaced a short distance below the collimating electrode 30, the central portion of the filamentary cathodes 25 and 26 being arranged in alignment with the transverse slots 31 and 32 formed in the collimating electrodes 29 and 30 and across the magnetic field.

The negative and positive terminals of the arc supply are respectively connected to the filamentary cathodes 25 and 26 and to the arc-block 22, and the collimating electrodes 29 and 30 are connected together by the frame member 70, and consequently by way of the arc-block 22 to the positive terminal of the arc supply mentioned, as previously noted. Finally, an upper shield 90 is connected to one of the terminals 80 and extends laterally over the upper surface of the central portion of the filamentary cathode 25 in order to prevent migration of the electrons

emitted by the filamentary cathode 25 upwardly in the longitudinal direction, and a lower shield 91 is supported by one of the terminals 82 and extends laterally beneath the lower surface of the central portion of the filamentary cathode 26 in order to prevent migration of the electrons emitted by the filamentary cathode 26 downwardly in the longitudinal direction.

Considering now the detailed operation of the calutron ion source 20, when the electric circuit for the heater 23 is completed, the charge receptacle 21 and consequently the charge bottle 63 are heated, whereby the charge 64 is vaporized, filling the cavity 62 in the charge receptacle 21. The vapor passes through the tubular member 67 into the vapor distributing chamber 65, whereby this chamber is filled with the vapor. The vapor is evenly distributed in the vapor distributing chamber 65 and passes around the side edges of the baffle plate 71 into the arc chamber 66, whereby this chamber is filled with the vapor. More particularly, the arc chamber 66 is thoroughly and uniformly filled with the vapor to be ionized, due to the arrangement of the vapor distributing chamber 65 and the baffle plate 71.

When the circuit for the filamentary cathodes 25 and 26 are completed, the filamentary cathodes 25 and 26 are heated and rendered electron emissive; and when the arc supply circuit is completed between the filamentary cathodes 25 and 26 and the arc-block 22, electrons are projected from the central portions of the filamentary cathodes 25 and 26 toward the respective collimating electrodes 29 and 30. More particularly, some of these electrons pass through the transverse slots 31 and 32 formed in the collimating electrodes 29 and 30 respectively, into the arc chamber 66. Accordingly, the collimating electrodes 29 and 30 cause two collinear streams of electrons having ribbon-like configurations to be projected into the arc chamber from opposite ends thereof, whereby the vapor in the arc chamber 66 is ionized. Moreover, the width of the streams of electrons is greater than the width of the upstanding slot 24 formed in the front wall 75, whereby any vapor flowing through the arc chamber 66 and the slot 24 must traverse the electron streams and thus be subjected to their ionizing influence. Thus a ribbon-like arc is produced in the zone between the two collimating slots and the electrons oscillate up and down along the magnetic field, gradually drifting to the side walls 74 of the frame member 70 and to the baffle plate 71. The positive ions produced in the arc chamber 66 are drawn through the upstanding slot 24 formed in the front wall 75 of the frame member 70 by the associated ion accelerating structure, whereby a beam of positive ions having a substantially ribbon-like configuration is projected into the adjacent end of the associated liner and directed toward the cooperating collector block.

In view of the foregoing, it is apparent that there has been provided an improved calutron, as well as an improved ion source, in which an arc discharge of more nearly uniform intensity throughout its length is produced.

While there has been described what is at present considered to be the preferred embodiment of the invention, it will be understood that various modifications may be made therein and it is intended to cover in the appended claims all such modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. An ion source comprising a hollow arc-block, means for establishing a magnetic field through said arc-block, said arc-block defining a gaseous region and having an elongated slit in the wall thereof aligned with said magnetic field and communicating with said region, means for supplying gas to be ionized into said region through an opening in said arc-block, a pair of apertured members at opposite ends of said arc-block, the openings in said members being aligned with said magnetic field, a

cathode disposed adjacent each of said apertured members for producing an arc discharge through each of said apertured members into said region, and means for withdrawing ions from said region through said slit transversely to said magnetic field.

2. An ion source comprising means for establishing a magnetic field, structure defining a gaseous region located in said magnetic field, means including a pair of cathodes respectively disposed on opposite sides of said region and aligned with said magnetic field and a pair of apertured anodes respectively disposed between said cathodes on opposite sides of said region and aligned with said cathodes for producing an arc discharge in said region, and means for withdrawing ions from said region transversely to said magnetic field.

3. Apparatus for producing ions of vaporizable materials comprising a receptacle for the material, means for heating and vaporizing said material, an elongated vapor compartment, tubular means connecting said vapor compartment with said receptacle, an elongated arc chamber connected to said vapor compartment by channels extending substantially throughout the length of said elongated arc chamber so that said vaporized material is fed to said arc chamber substantially uniformly throughout the length of said arc chamber, said arc chamber having an aperture at the top and one at the bottom thereof, a pair of cathodes, said cathodes being positioned one over each of said apertures in said arc chamber, said apertures having areas substantially less than the electron emitting areas of said cathodes projected thereon so that electrons projected into said arc chamber through said apertures are in the form of wide ribbon-like beams for ionizing the vapor in said arc chamber.

4. Apparatus for producing ions of vaporizable materials comprising a receptacle for the material, a heating unit adapted to be electrically energized for vaporizing said material in said receptacle, an elongated box-like container, a baffle extending substantially over the length of said container for dividing said container into a rear vapor compartment and a front arc compartment, tubular means for feeding vapor from said receptacle to said rear vapor compartment, said rear compartment being connected to said front arc compartment by channels extending substantially throughout the length of said container along the sides of said baffle so that vapor from said vapor compartment is fed to said front arc compartment substantially uniformly throughout the length of said front arc compartment, and means for producing a pair of electron beams in said front arc compartment for ionizing the vapor fed into said front arc compartment, said last mentioned means comprising a pair of cathodes each positioned over a collimating aperture formed in a wall of said arc compartment, said apertures each having an area substantially less than the projection thereon of the electron emitting surface of the cathode associated therewith whereby the electrons entering said arc compartment are in the form of ribbon-like beams.

5. Apparatus for producing ions of gaseous materials comprising a receptacle for the material, an elongated compartment, tubular means connecting said elongated compartment with said receptacle, an elongated arc chamber connected to said compartment by channels extending substantially throughout the length of said elongated arc chamber so that said gaseous material is fed to said arc chamber substantially uniformly throughout the length of said arc chamber, a pair of cathodes, said arc chamber having apertures at each end thereof and a slot in the front thereof, said cathodes being positioned adjacent said apertures for collimating the electron beams projected into said arc chamber from said cathodes, said apertures being dimensioned so that the areas thereof are substantially less than the areas of the projections thereon of the electron emitting surfaces of the respective cathodes, and means for drawing the ions out of said arc chamber through said slot.

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6. Apparatus for producing ions of gaseous materials comprising a receptacle for the material, an elongated box-like container, a baffle extending substantially over the length of said container for dividing said container into a rear compartment and a front arc compartment, tubular means for feeding gaseous material from said receptacle to said rear compartment, said rear compartment being connected to said front arc compartment by channels extending substantially throughout the length of said container along the sides of said baffle so that gaseous material from said rear compartment is fed to said front arc compartment substantially uniformly throughout the length of said front arc compartment, and means for producing a pair of electron beams in said front arc compartment for ionizing the vapor fed into said front arc compartment, said last mentioned means comprising a pair of cathodes positioned over apertures formed in the end walls of said arc compartment, each of said apertures having areas substantially less than the areas of the projections thereon of the electron emitting areas of the respective cathodes for collimating the electron streams projected from said cathodes into said arc compartment.

7. Apparatus for producing ions of gaseous materials comprising a receptacle for the material, an elongated compartment, tubular means connecting said elongated compartment with said receptacle, an elongated arc chamber connected to said compartment by channels extending substantially throughout the length of said elongated arc chamber so that said gaseous material is fed to said arc chamber substantially uniformly throughout the length of said arc chamber, a pair of cathodes, said arc chamber having collimating apertures at each end thereof and a slot in the front thereof, said cathodes being positioned adjacent said apertures and said apertures being dimensioned so that the areas thereof are substantially less than the areas of the projections thereon of the electron emitting surfaces of the respective cathodes, shield means positioned adjacent to each of said cathodes on the sides opposite to said apertures, and means for drawing the ions out of said arc chamber.

8. Apparatus for producing ions comprising a receptacle for the material, an elongated box-like container, a baffle extending substantially over the length of said container for dividing said container into a rear compartment

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and a front arc compartment, tubular means for feeding gaseous material from said receptacle to said rear compartment, said rear compartment being connected to said front arc compartment by channels extending substantially throughout the length of said container along the sides of said baffle so that gaseous material from said rear compartment is fed to said front arc compartment substantially uniformly throughout the length of said front arc compartment, and means for producing a pair of electron beams in said front arc compartment for ionizing the vapor fed into said front arc compartment, said last mentioned means comprising a pair of cathodes positioned over apertures formed in the end walls of said arc compartment, each of said apertures having areas substantially less than the areas of the projections thereon of the electron emitting areas of the respective cathodes for collimating the electron streams from said cathodes into said arc compartment, shield means positioned adjacent to each of said cathodes on the sides opposite to said apertures, and means for drawing the ions out of said arc compartment through a narrow slot formed in the front wall thereof.

9. An ion source comprising means for establishing a magnetic field, structure defining a gaseous region located in said magnetic field, a pair of cathodes respectively disposed on opposite sides of said region, a pair of apertured members disposed between said cathodes on opposite sides of said region, a source of electrical potential connected between said cathodes and said apertured members for producing a ribbon-like arc discharge in said region, and means for withdrawing ions from said region transversely to said magnetic field.

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