Jan. 28, 1958 B. T. WRIGHT 2,821,632

APPARATUS FOR PRODUCING IONS OF VAPORIZABLE MATERIALS

Filed Sept. 25, 1944 2 Sheets-Sheet 1

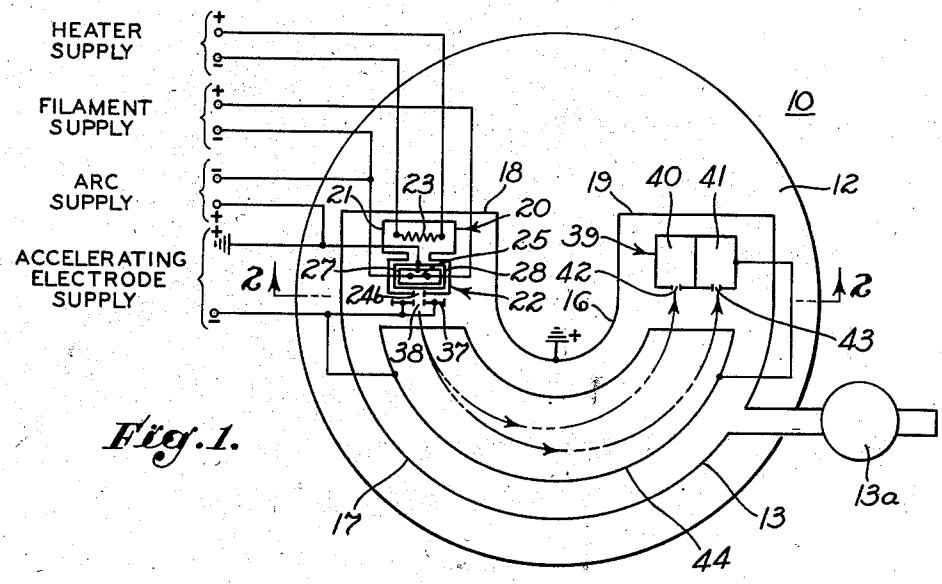

Fig. 1.

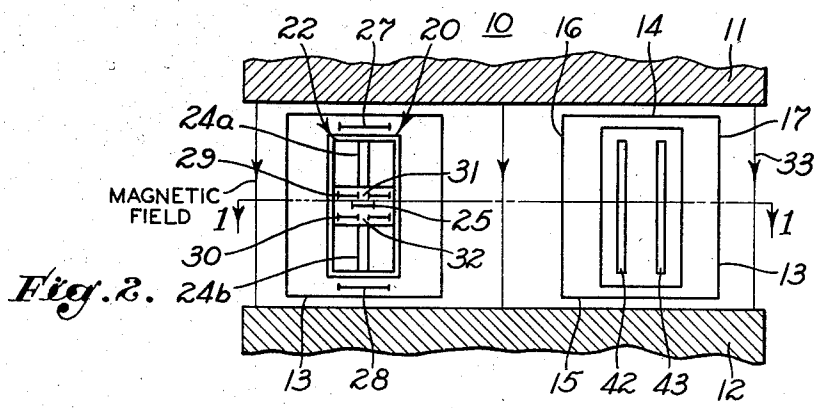

Fig. 2.

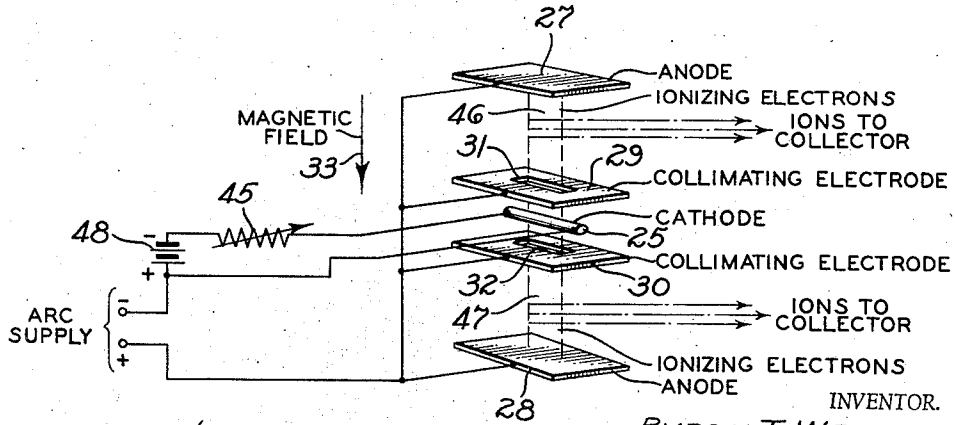

Fig. 3.

INVENTOR.
BYRON T. WRIGHT
BY Robert A. Lawrence
ATTORNEY.

Jan. 28, 1958 B. T. WRIGHT 2,821,632

APPARATUS FOR PRODUCING IONS OF VAPORIZABLE MATERIALS

Filed Sept. 25, 1944 2 Sheets-Sheet 2

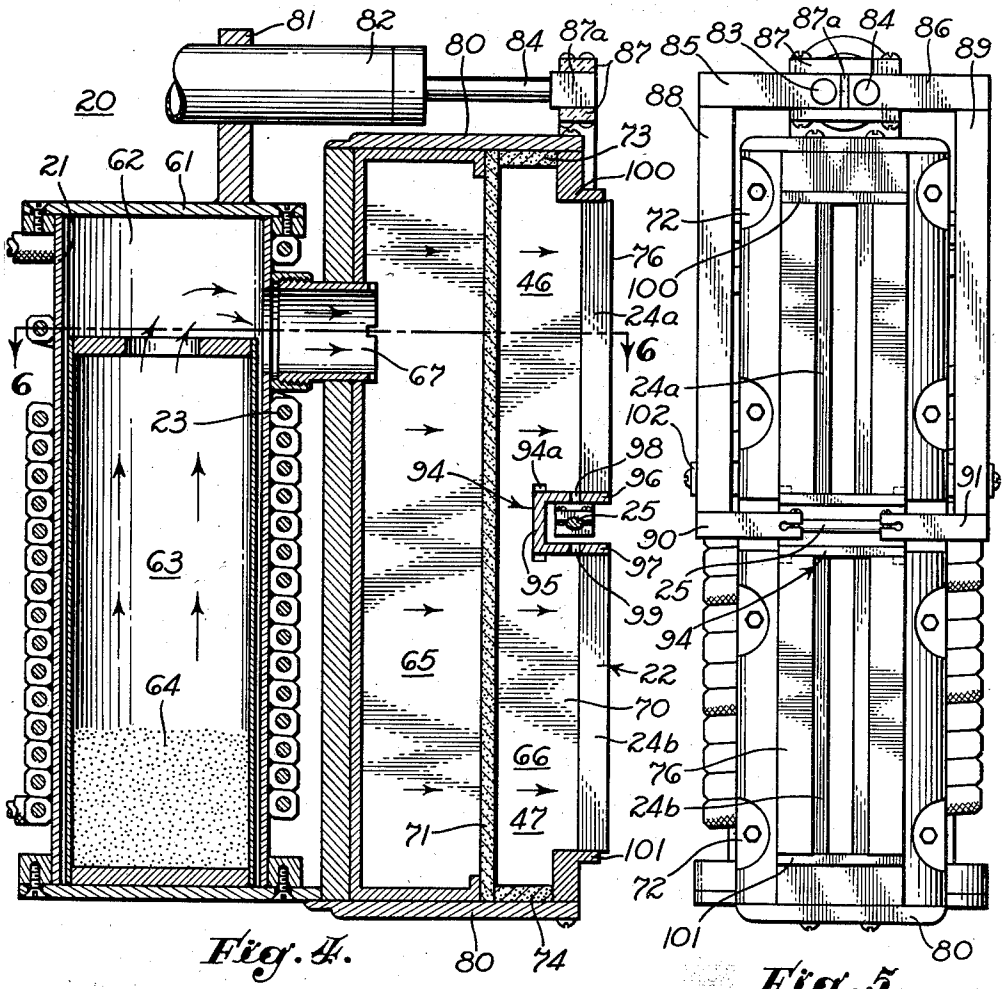

Fig. 4.

Fig. 5.

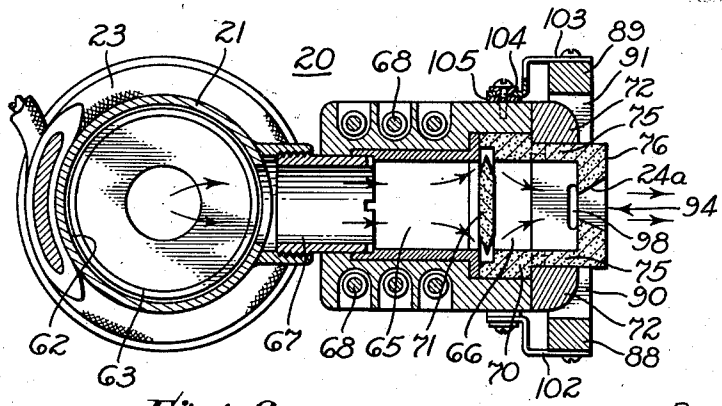

Fig. 6.

INVENTOR.
BYRON T. WRIGHT
BY
ATTORNEY.

United States Patent Office 2,821,632
Patented Jan. 28, 1958

2,821,632

APPARATUS FOR PRODUCING IONS OF VAPORIZABLE MATERIALS

Byron T. Wright, Berkeley, Calif., assignor to the United States of America as represented by the United States Atomic Energy Commission

Application September 25, 1944, Serial No. 555,615

13 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 disposed in a magnetic field, with a pair of gas ionizing devices for producing ionization along an extended line aligned with the magnetic field.

Another object of the invention is to provide an improved ion source having a gaseous region disposed in a magnetic field with an electron source in the region, and means for projecting electrons from the source into the gaseous region in opposite directions along the magnetic field to produce two collinear arc discharges.

A further object of the invention is to provide an electric discharge device having a gaseous region disposed in a magnetic field and an electron source in the region with means for projecting two beams of electrons of well-defined cross section in opposite directions along the magnetic field to produce a pair of collinear arc discharges in the gaseous region.

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

A still further object is to provide an improved ion source unit with an electrode arrangement of rugged construction.

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 sectional plan view of a calutron, taken along the line 1—1 in Fig. 2, 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 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 elevation 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 of 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, now U. S. Patent No. 2,709,222, 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 U^{235}.

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 unionized 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.

In accordance with the present invention, an improved ion source is provided in which electrons are projected into the vapor-containing region of the arc-block as two collinear streams, whereby the electrons encounter and ionize molecules of the vapor introduced into said region. Preferably, the ion source comprises a single thermionically emissive cathode disposed intermediate the ends of the vapor-containing region, cooperating with an arrangement of electrodes for projecting electrons from the cathode in opposite directions along the magnetic field extending through the vapor-containing region. In the preferred embodiment, anodes are arranged on opposite sides of the thermionically emissive cathode in line therewith along the magnetic field, and a pair of apertured electrodes are disposed respectively also on opposite sides of the cathode, adjacent thereto, and between the cathode and the respective anodes. The dimensions of the cathode and the openings in the apertured electrodes are proportioned to define arc discharges of uniform cross section throughout the discharges lengths. The cathode and the openings in the apertured electrodes and anodes are substantially in alignment with the magnetic field extending through the aforesaid vapor-containing region. With such an electrode arrangement, a pair of arc discharges of uniform cross sections are produced in the vapor-containing region, and the regions of ionization in which these arc discharges are effective are of an extended length and of substantially uniform cross section throughout. Therefore when such an ion source is used in a calutron, an arc of effectively increased length is obtained, and the efficiency and economy of commercial calutron operation is increased.

Referring now more particularly to Figs. 1 and 2 of the drawings, there is illustrated a calutron provided with an ion source 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 opposite ends of the tubular tank and are adapted to be removably secured in place, whereby the tank 13 is hermetically sealed. Also, vacuum pumping apparatus 13*a* 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 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, being provided with upper and lower collinear upstanding slots 24*a* and 24*b* respectively, formed in the front 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 and with the tank.

The ion source unit is provided with a filamentary cathode 25 adapted to be connected to a suitable source of filament supply, the filamentary cathode 25 being disposed within the cavity formed in the arc-block 22 and approximately halfway between the ends thereof between the two upstanding slots 24*a* and 24*b*. The ion source unit also is provided with a pair of anodes 27 and 28, the upper anode 27 being disposed substantially at the upper end of the arc-block 22 to define the upper end of the slot 24*a* and the lower anode 28 being disposed substantially at the lower end of the arc-block 22 to define the lower end of the slot 24*b*. Further, the ion source unit includes a pair of apertured collimating electrodes 29 and 30, respectively disposed on opposite sides of the cathode 25 and adjacent thereto substantially within the cavity formed in the arc-block 22, the upper collimating electrode 29 being disposed at the lower end of the upper slots 24*a*, and the lower collimating electrode 30 being disposed at the upper end of the lower slot 24*b*. The respective collimating electrodes 29 and 30 have elongated transversely extending collimating slots 31 and 32 therethrough, said slots being aligned with the filamentary cathode 25 across the magnetic field 33. The anodes 27 and 28, the collimating electrodes 29 and 30, the arc-block 22 and charge receptacle 21 are electrically connected to the positive terminal of the arc current supply and grounded. Likewise, the tank 13 is grounded. Also, the filamentary cathode 25 is connected to the negative terminal of the aforesaid 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 front wall of the arc-block 22 in which the slots 24*a* and 24*b* are formed. A slit 38 is formed in the ion accelerating electrode 37 and arranged in substantial alignment with respect to the slots 24*a* and 24*b* formed in the wall of the arc-block 22. A suitable source of accelerating electrode potential supply is adapted to be connected between the arc-block 22 and the ion accelerating electrode 37, the positive and negative terminals of the potential supply source being connected to the arc-block 22 and to the ion accelerating electrode 37, respectively. Further, the positive terminal of the ion accelerating electrode potential supply 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 slots 42 and 43 formed in the front 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 transverse cross section, disposed within the tank 13 and spaced from the walls 14, 15, 16, and 17. One end of the tubular liner 44 is positioned adjacent the accelerating electrode structure 37 and the other end is disposed adjacent the collector block 39; the tubular liner 44 functions as an electrostatic shield for the high velocity ions traversing the curved paths between the slit 38 formed in the ion accelerating electrode 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 electrode structure 37, the tubular liner 44, and the collector block 39 are connected to the ungrounded negative terminal of the accelerating electrode potential supply; the ion accelerating electrode structure 37, the tubular liner 44, and the collector block 39 being electrically insulated from the tank 13 and the ion source unit 20.

Referring now more particularly to Fig. 3 of the drawings, the electrode arrangement of the calutron ion source 20 embodying the features of the present invention is illustrated schematically in perspective. More particularly, this electrode arrangement comprises, among other elements, a straight filamentary cathode 25, formed of tungsten, tantalum or the like, a pair of apertured plate-like collimating electrodes 29 and 30 formed of tungsten, molybdenum or the like, positioned on opposite sides of the filamentary cathode 25, and a pair of anodes 27 and 28 positioned on opposite sides of the plate-like collimating electrodes 29 and 30 and at distances therefrom relatively large compared to the distances from the filamentary cathode 25 to the collimating electrodes 29 and 30. 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 anodes 27 and 28 are arranged in substantially parallel longitudinal spaced-apart relation and are positioned with the major faces thereof transverse to the magnetic field mentioned; the collimating electrodes 29 and 30 are arranged between the anodes 27 and 28 in substantially parallel relation therewith and also disposed with the major faces thereof transverse to the magnetic field mentioned. The collimating electrodes 29 and 30 have elongated collimating slots 31 and 32 formed therethrough, said slots being disposed parallel to the central portion of the filamentary cathode 25 disposed between said collimating electrodes. Accordingly, the filamentary cathode 25, the collimating electrodes 29 and 30, and the anodes 27 and 28 are respectively disposed in five substantially parallel planes, spaced apart longitudinally and disposed substantially normal to the magnetic field mentioned. Furthermore, the central portion of the filamentary cathode 25 and the slots 31 and 32 formed in the collimating electrodes 29 and 30 are arranged in alignment with the magnetic field mentioned.

The slots 31 and 32 formed in the collimating electrodes 29 and 30 are narrower than the central portion of the filamentary cathode 25. Furthermore these slots are shorter than the filamentary cathode in the direction along the length of the filament 25, whereby the dimensions of said slots are less than the corresponding dimensions of the filamentary cathode 25. Thus, an ion source is provided having a central cathode and an arrangement of electrodes symmetrically disposed on opposite sides of the cathode for projecting ionizing electrons in opposite directions as two collinear beams into a region containing vapor to be ionized.

The filamentary cathode 25 is electrically connected by way of an adjustable resistor 45 to a corresponding source of filament current supply indicated as a battery 48. The filamentary cathode 25 is connected to the negative termi-

nal of the arc current supply; and the anodes 27 and 28 are connected to the positive terminal of said arc current supply. The collimating electrodes 29 and 30 are electrically connected to the anodes 27 and 28, and to the arc-block 22 as previously noted, whereby upper and lower substantially electric-field-free zones 46 and 47 are defined in the gaseous region formed by the cavity in the arc-block 22, the upper electric-field-free zone 46 being between the upper collimating electrode 29 and the upper anode 27, and the lower electric-field-free zone 47 being formed between the lower collimating electrode 30 and the lower anode 28.

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 and the tank is hermetically sealed. The various electrical connections are completed and operation of the vacuum pumping apparatus 13*a* 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, so that 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 and into the two zones 46 and 47 mentioned. The electric circuit for the filamentary cathode 25 is closed, whereby the filamentary cathode 25 is heated and rendered electron emissive. Then, the electric circuit between the filamentary cathode 25 and the arc-block 22 is closed, rendering the filamentary cathode 25 negative with respect to the collimating electrodes 29 and 30 and to the anodes 27 and 28 and to the arc-block 22. Accordingly, electrons are projected from the filamentary cathode 25 in opposite directions toward the corresponding collimating electrodes 29 and 30 along the magnetic field. Some of these electrons pass through the slots 31 and 32 formed in the collimating electrodes 29 and 30 and continue into the two substantially electric-field-free zones 46 and 47 in the cavity formed in the arc-block 22 between the collimating electrodes 29 and 30 and the respective adjacent anodes 27 and 28, whereby the gas or vapor in the zones 46 and 47 in the cavity formed in the arc-block 22 on opposite sides of the filamentary cathode 25, is ionized. The electrons proceeding from the filamentary cathode 25 through the collimating slots 31 and 32 in the collimating electrodes 29 and 30 encounter molecules of the vapor in the two zones 46 and 47 of the cavity formed in the arc-block 22 and 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.

More specifically, the electrons projected from the filamentary cathode 25 gain substantially all of their energy in traversing the electric field between the filamentary cathode 25 and the two collimating electrodes 29 and 30, whereby they enter the two zones 46 and 47 in the gaseous or vapor region in the cavity formed in the arc-block 22 at velocities sufficient to produce ionization of the gas or vapor. Moreover, the electrons traveling into the vapor region through the collimating slots 31 and 32 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 substantially 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 cathode 25, the cross sections of the electron streams entering the zones 46 and 47 of the gaseous region respectively disposed between the collimating electrodes 29 and 30 and the corresponding adjacent anodes 27 and 28 are positively defined, and only electrons from the uniform electron-emissive surface of the central portion of the filamentary cathode 25 are employed. These uniform and steady streams of electrons projected into the zones 46 and 47 of the gas or vapor region mentioned result in a pair of arc discharges therethrough along the magnetic field and opposite the slots 24*a* and 24*b* formed in the front wall of the arc-block 22, whereby a uniform and copious supply of positive ions is produced in the two zones 46 and 47 mentioned. Each of these arc discharges is characterized by a high current, a low voltage drop, and a luminous plasma. More specifically, most of the electrons projected from the filamentary cathode 25 through the slots 31 and 32 in the collimating electrodes 29 and 30 proceed to the respective anodes 27 and 28, thereby to complete the circuit between the positive and the negative terminals of the arc supply, current in the arc discharges flowing from the anodes 27 and 28 to the filamentary cathode 25.

Due to the construction and arrangement of the electrodes of the ion source 20, the streams of electrons proceeding from the filamentary cathode 25 through the slots 31 and 32 formed in the collimating electrodes 29 and 30 form two collinear ribbon-like configurations, within the boundaries of which most of the positive ions formed in the gas or vapor region are concentrated. This arrangement produces a uniform and copious supply of positive ions, and these are adapted to be fed to the slots 24*a*, 24*b* in the wall of the arc-block 22 with which the ion accelerating structure 37 is operatively associated.

The electric circuit between the arc-block 22 and the ion accelerating structure 37 is then completed, the accelerating structure 37 being at a high negative potential with respect to the arc-block 22, whereby the positive ions in the upper and lower zones 46 and 47 in the arc-block 22 are attracted by the ion accelerating structure 37 and accelerated through the voltage impressed therebetween to form two beams of ions. More particularly, the positive ions proceed from the upper ionization zone 46 in the cavity formed in the arc-block 22, through the upper slot 24*a* 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 as an upper beam into the interior of the tubular liner 44. Likewise, the positive ions proceed from the lower ionization zone 47 in the cavity formed in the arc-block 22, through the lower slot 24*b* 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 as a lower beam into the interior of the tubular liner 44. When ions in the two beams of high-velocity positive ions pass through the accelerating structure 37, they merge to form a single vertical upstanding beam proceeding from the arc source 20 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 to the accelerating electrode 37 are deflected from their normal straight-line path and from a vertical plane passing through the center of the slots 24*a* and 24*b*, and the center of the aligned slit 38, by 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 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 **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 different dimensions of the parts of the calutron **10**, the various electrical potentials applied between the electrodes and 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 several 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 dominent constituent of normal uranium. Furthermore, the deposit of uranium collected in the pocket **40** of the collector block **39** contains a considerably increased mount 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 example 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 discharges within the cavity in the arc-block **22** must be both relatively intense and uniform. Moreover, it is desirable that such arc discharges 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 a stable beam of positive ions of increased intensity by producing two stable and intense collinear arcs along the magnetic field, and thus effectively produces a uniform and intense arc discharge of increased length.

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 **20** 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** therein, 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 consequently 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, 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.

More particularly, the wall structure of the arc-block **22** comprises a rectangular-shaped frame member **70**, supporting an upstanding baffle plate **71**, the frame member **70** and the baffle plate **71** being formed of carbon or graphite. The frame member **70** is secured to the wall structure of the arc-block **22** by four upstanding strips **72**, and comprises a top wall **73**, a bottom wall **74**, two upstanding substantially parallel spaced-apart side walls **75**, and a front wall **76**, the front wall **76** having centrally disposed longitudinal slots **24***a* and **24***b* 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 **75** of the frame member **70** in order to provide communicating channels between the vapor distributing chamber **65** and the arc chamber **66** on each vertical side of the baffle plate. The rectangular frame member **70** and the baffle plate **71** are supported in the arc-block **22** by means of the upper and lower end plates **80** of the wall structure of the arc-block **22**.

The wall structure of the charge receptacle **21** carries a standard **81** which supports the cathode structure in cooperating relationship with respect to the arc-block. The cathode structure comprises a tubular arm **82** carrying a pair of heavy current conductors **83** and **84** insulated from each other by insulation strips **87** and connected to a pair of horizontal arms **85** and **86**, the ends thereof separated by an insulating strip **87***a*. The horizontal arms **85** and **86** are secured to the conductors **83** and **84** respectively by screws and extend parallel to the front wall **76** of the arc-block **22**. Two depending arms **88** and **89** are secured respectively to the ends of the transversely extending arms **85** and **86** on opposite sides of the arc-block **22**, and two horizontal inwardly extending arms **90** and **91** are secured to the lower ends of the depending arms **88** and **89** respectively. The two inwardly extending arms **90** and **91** extend through two slots **92** and **93**.

respectively, cut through the front wall **76** and through portions of the side walls **75** of the frame member **70**. The inner ends of the inwardly extending arms **90** and **91** provide terminals for rigidly holding the filamentary cathode **25**. The arms **85**, **88**, and **90**, provide electrical connection between one conductor **83** and one end of the filamentary cathode **25**; and the arms **86**, **89**, and **91** provide electrical connection between the other conductor **84** and the other end of the filamentary cathode **25**. The opposite ends of the filamentary cathode **25** are removably clamped in place by the respective terminals formed in the inward ends of the inwardly extending arms **90** and **91**, these two terminals being connected to a suitable source of filament supply, as previously noted. It will be noted that the arms **85**, **86**, **88**, **89**, **90**, and **91** of the cathode support structure lie in a plane parallel to the face of the front wall **76** of the arc-block **22**, the median plane through the support structure mentioned and the axis of the filament passing through the arc chamber **66** a short distance from the interior surface of the front wall **76**.

Supported in a transverse slot through the front wall **76** and through portions of the side walls **75** of the frame member **70** is a collimating electrode structure **94** corresponding to the aperture electrodes **29** and **30** of Fig. 3. The collimating electrode structure **94** in this case is of U-shaped cross section in a plane parallel to the magnetic field and perpendicular to the front wall **76** of the frame member **70**. Small projections **94***a* are provided on the corners of the top and bottom walls of the collimating electrode structure **94** and these projections fit into corresponding slots in the side walls **75** to retain the structure **94** in position. The collimating electrode structure is provided with an end wall **95** between the filament **25** and the baffle plate **71** and upper and lower walls **96** and **97** on opposite sides of the filament **25**, the end wall **95** and the upper and lower walls **96** and **97** forming the collimating electrode structure being formed of tungsten, or molybdenum, or the like. The upper and lower walls **96** and **97** have transversely extending slots **98** and **99** formed therethrough, corresponding to slots **31** and **32** of Fig. 3, and communicating with upper and lower zones **46** and **47**, respectively, of the arc chamber **66**. The lengths of these two transversely extending slots are greater than the width of the slots **24***a* and **24***b* formed in the front wall **76** of the arc-block **22**. Furthermore these two collimating slots **98** and **99** are substantially parallel to the filamentary cathode **25** above and below said cathode, as previously noted, and serve to collimate the electron beams projected from the filamentary cathode **25** in opposite directions along the magnetic field. The widths and lengths of the transverse slots **98** and **99** are respectively less than the width and length of the filamentary cathode **25** as hereinabove explained. Anodes **100** and **101** extending into the arc chamber **66** in alignment with the central portion of the filamentary cathode **25** and in alignment with the transverse slots **98** and **99** formed in the collimating electrode structure, are supported by the top and bottom walls **80** and attached thereto by suitable screws.

Brackets **102** and **103** are attached to the vertical cathode supporting bus bars **88** and **89**, respectively, and to the sides of the arc-block **22** by suitable screws to hold these bus bars and the cathode **25** in fixed relation with respect to the collimating structure and particularly the collimating apertures **98** and **99**. These brackets **102** and **103** are insulated from the arc-block **22** by suitable insulation bushings **104** and **105**, respectively, of heat resistant material.

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 through the channels around the side edges of the baffle plate **71** into the arc chamber **66**, whereby this chamber and hence the two zones **46** and **47** thereof are 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 **66**.

When the circuit for the filamentary cathode **25** is completed, the filamentary cathode **25** is heated and rendered electron emissive; and when the arc supply circuit is completed between the filamentary cathode **25** and the arc-block **22**, electrons are projected from the central portion of the filamentary cathode **25** toward the upper and lower walls of the collimating electrode structure **94**. More particularly, some of these electrons pass through the transverse slots **98** and **99** formed in the upper and lower walls **96** and **97** of the collimating electrode structure **94**, into the upper and lower zones **46** and **47**, respectively, in the arc chamber **66**. Accordingly, two collinear streams of electrons having ribbon-like configurations are projected into the two gas or vapor filled zones **46** and **47** in the arc chamber **66**, whereby the gas or vapor in the zones **46** and **47** is ionized. Moreover, the width of the streams of electrons is greater than the width of the upstanding slots **24***a* and **24***b* formed in the front wall **76**, whereby any vapor flowing through the arc chamber **66** and the slots **24***a* and **24***b* must traverse the electron streams and thus be subjected to their ionizing influence. Thus, two ribbon-like arcs are produced in the respective zones **46** and **47** at the upper and lower ends of the arc chamber **66**. The positive ions produced in the zones mentioned are drawn through the upstanding slots **24***a* and **24***b* formed in the front wall **76** of the frame member **70** by the associated ion accelerating structure **37**, whereby two beams of positive ions having a substantially ribbon-like configuration are projected through the accelerating electrode structure **37**, there to merge and be projected as a single beam into the adjacent end of the associated liner **44** and directed toward the cooperating collector block **39**, as hereinabove explained.

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 effectively greater length and of uniform and stable character 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 having a region for receiving gas to be ionized and having at least one 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, gas ionizing means for producing a pair of collinear arc discharges in said region aligned with said magnetic field, and means for withdrawing ions from said region through said slit.

2. An ion source comprising a hollow arc-block, means for establishing a magnetic field through said arc-block, said arc-block having a region for receiving gas to be ionized and having an elongated slit in a 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, means for projecting two oppositely directed streams of electrons aligned with said magnetic field into two zones of

said region, whereby gas in said zones is ionized, and means for withdrawing ions from said zones through said slit.

3. An ion source comprising a hollow arc-block, means for establishing a magnetic field through said arc-block, said arc-block having a region for receiving gas to be ionized and having an elongated slit in a 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, means for projecting a plurality of collinear streams of electrons aligned with said magnetic field into different zones of said region, whereby gas in said zones is ionized, and means for withdrawing ions from said zones through said slit.

4. An ion source comprising a hollow arc-block, means for establishing a magnetic field through said arc-block, said arc-block having a region for receiving gas to be ionized and having an elongated slit in a 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 cathode located within said region, means for projecting electrons from said cathode in opposite directions along said magnetic field into two zones of said region, whereby gas in said zones is ionized, and means for withdrawing ions from said zones through said slit.

5. An ion source comprising a hollow arc-block, means for establishing a magnetic field through said arc-block, said arc-block having a region for receiving gas to be ionized and having an elongated slit in a 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 cathode located within said region, means for projecting electrons from said cathode in opposite directions along said magnetic field into two zones of said region, whereby two arc discharges are respectively produced in said two zones, two apertured electrodes respectively disposed on opposite sides of said cathode and adjacent thereto and defining the respective cross sections of said arc discharges, and means for withdrawing ions from said zones through said slit.

6. An ion source comprising means for establishing a magnetic field, structure defining a gaseous region located in said magnetic field, a cathode disposed within said region, a pair of anodes disposed on opposite sides of said cathode along a line parallel to said magnetic field, means for producing an arc discharge between said cathode and each of said anodes, and means for withdrawing ions from said region transversely of said magnetic field.

7. An ion source comprising means for establishing a magnetic field, structure defining a gaseous region located in said magnetic field, a cathode disposed within said region, a pair of anodes disposed on opposite sides of said cathode along a line parallel to said magnetic field, means for producing an arc discharge between said cathode and each of said anodes, an apertured member disposed intermediate said cathode and said anodes and defining the cross sections of said arc discharges, and means for withdrawing ions from said region transversely of said magnetic field.

8. Apparatus for producing ions of vaporizable material 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, a cathode positioned in said arc chamber, a pair of anodes in said arc chamber, and sources of current supply for energizing said cathode and said anodes to produce collimated ribbon-like electron discharges from said cathode to said anodes to set up arcs through said vapor in said arc chamber and ionize said vapor.

9. Apparatus for producing ions of a material 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 uniform throughout the length of said arc chamber, a cathode positioned in said arc chamber, a pair of anodes in said arc chamber, and a pair of apertured collimating electrodes, one of said apertured electrodes being between said cathode and one of said anodes and the other of said apertured electrodes being between said cathode and the other of said anodes, said apertured collimating electrodes having apertures proportioned with respect to said cathode to collimate the electrons from said cathode into ribbon-like beams projected into said arc chamber for ionizing said vaporized material.

10. Apparatus for producing ions of vaporizable material 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 asid 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 slot means in the front thereof, a cathode positioned in said arc chamber substantially midway between the top and the bottom thereof, a pair of anodes in said arc chamber, one of said anodes being near the top and the other of said anodes being near the bottom of said arc chamber, collimating electrode means above and below said cathode sources of current supply for energizing said cathode, collimating electrodes and said anodes to produce sheet-like electron discharges from said cathode to said anodes immediately behind said slot means to set up arcs through said vapor in said arc chamber and ionize said vapor, and means for drawing ions out of said slot means.

11. Apparatus for producing ions of a material 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 collimated ribbon-like electron beams in said front arc compartment for ionizing the vapor fed into said front arc compartment.

12. Apparatus for producing ions of a gaseous material comprising a receptacle for the gaseous 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 the 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 collimated ribbon-like electron beams in said front arc compartment for ionizing the vapor fed into said front arc compartment.

13. Apparatus for producing ions of vaporizable material 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 font 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 cathode located in said arc compartment substantially midway between the ends thereof, a housing for substantially enclosing said cathode, said housing having apertures in the sides thereof facing the ends of said arc compartment for collimating the electrons from said cathode into beams, and anodes positioned substantially in the ends of said arc compartment.

References Cited in the file of this patent

UNITED STATES PATENTS

2,011,922	Von Wedel	Aug. 20, 1935
2,061,254	Rockwood	Nov. 17, 1936
2,225,047	Harnish	Dec. 17, 1940
2,244,672	Brett	June 10, 1941
2,257,794	Garner	Oct. 7, 1941
2,300,436	Skellett	Nov. 3, 1942
2,355,658	Lawlor	Aug. 15, 1944
2,373,151	Taylor	Apr. 10, 1945