Nov. 19, 1957 C. STARR 2,813,979

APPARATUS FOR PRODUCING IONS OF VAPORIZABLE MATERIALS

Filed Sept. 25, 1944 2 Sheets-Sheet 1

Fig. 1.

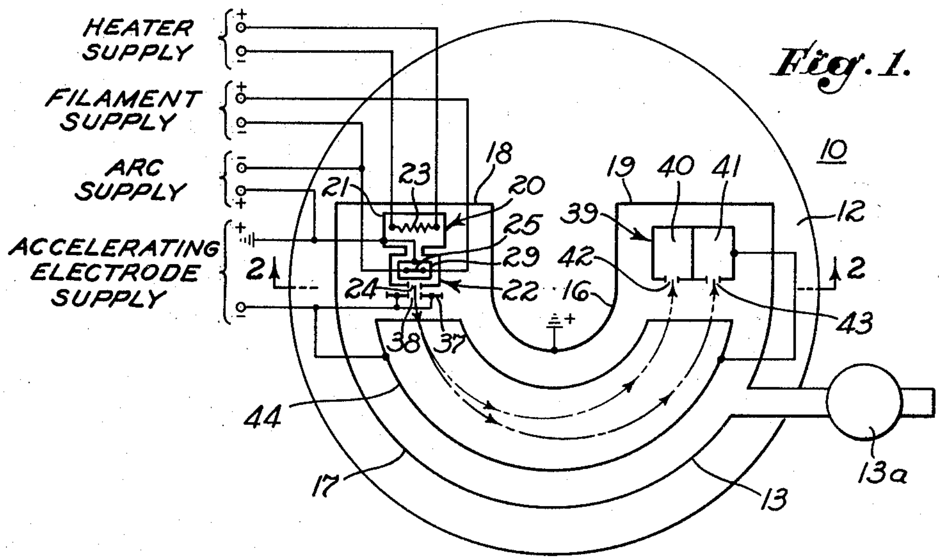


Fig. 2.

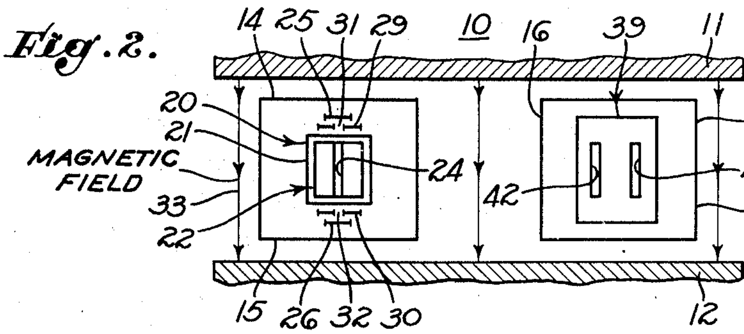
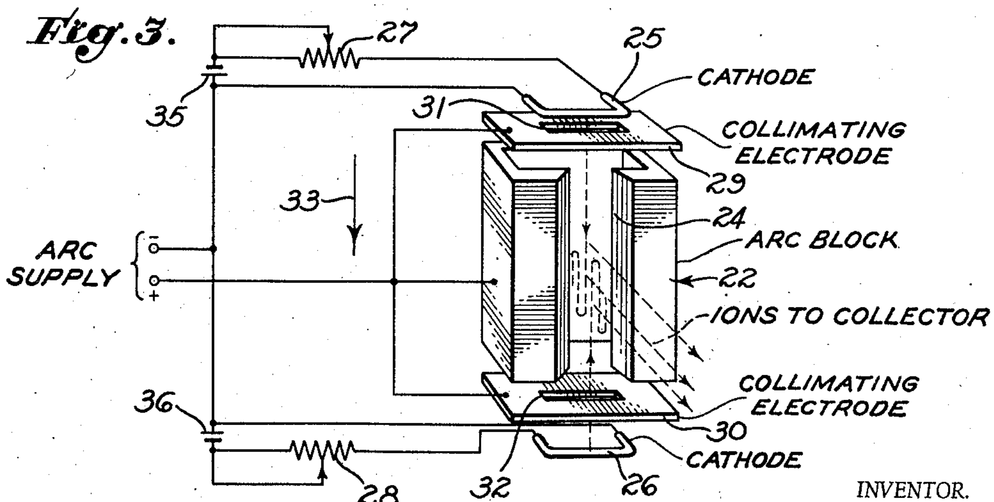


Fig. 3.



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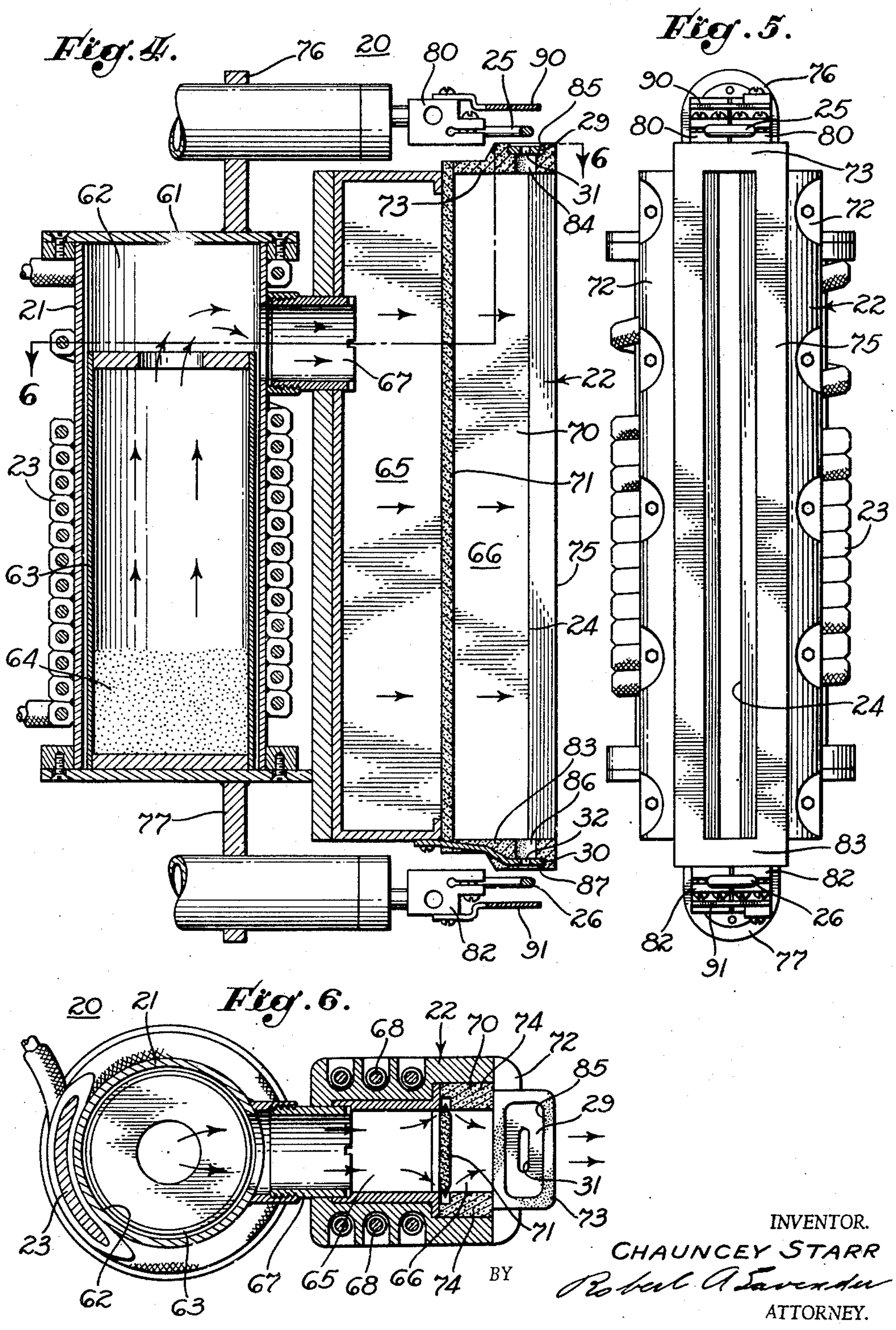
Filed Sept. 25, 1944 2 Sheets-Sheet 2



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APPARATUS FOR PRODUCING IONS OF VAPORIZABLE MATERIALS

Chauncey Starr, Berkeley, Calif., assignor to the United States of America as represented by the United States Atomic Energy Commission

Application September 25, 1944, Serial No. 555,614

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 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 un-ionized vapor and for accelerating the segregated ions to relatively high velocities; electromagnetic means for deflecting the ions along curved paths, the radii of curvature of the paths of the ions being proportional to the square roots of the masses of the ions, whereby the ions are concentrated in accordance with their masses; and means for de-ionizing and collecting the ions of the selected isotope thus concentrated, thereby to produce a deposit of the element enriched with the selected isotope.

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 **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 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 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 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 **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, 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 susbtantially 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.

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 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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