Sept. 13, 1955 L. F. WOUTERS 2,717,962

ELECTRIC DISCHARGE DEVICES

Filed March 31, 1944 2 Sheets-Sheet 1

Fig. 1.

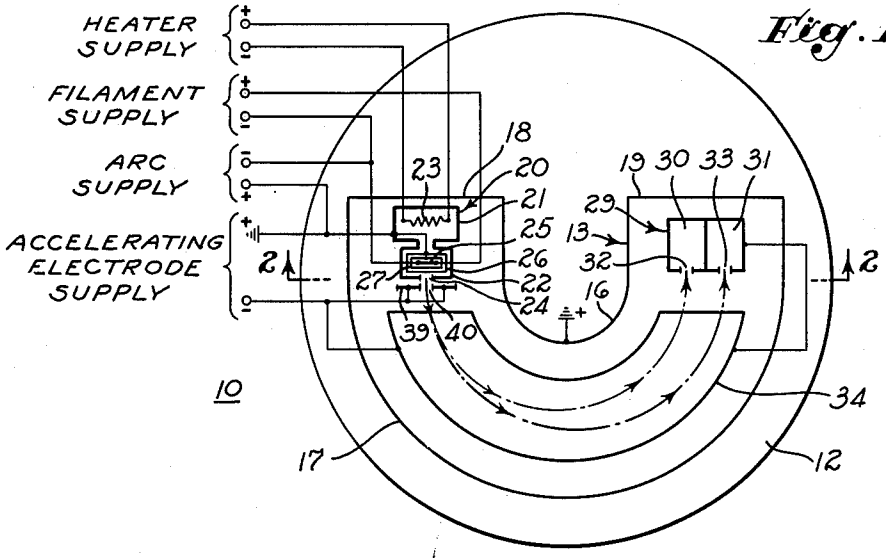


Fig. 2.

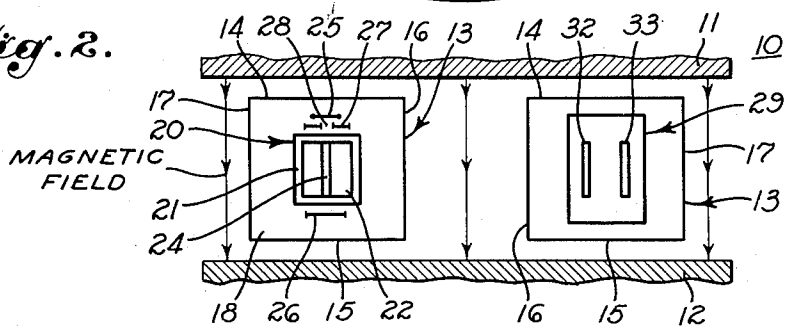
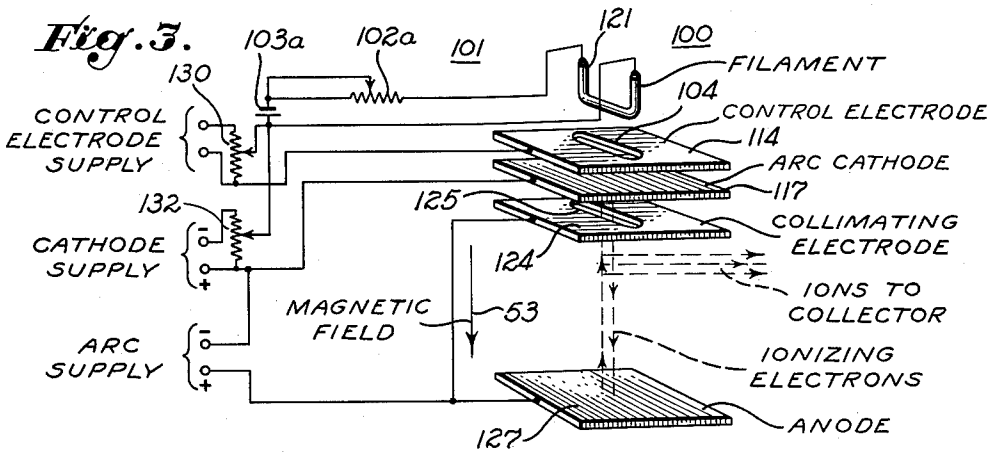


Fig. 3.



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Fig. 4.

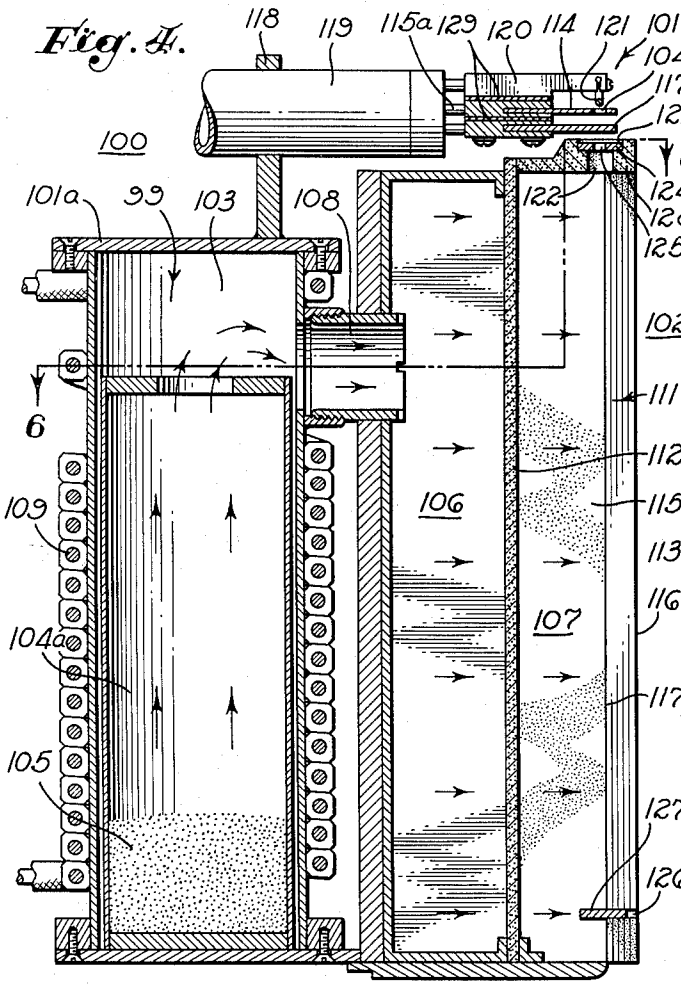


Fig. 5.

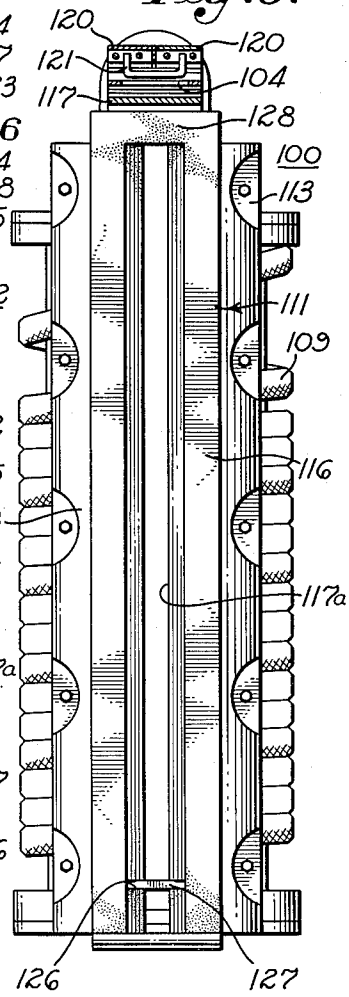
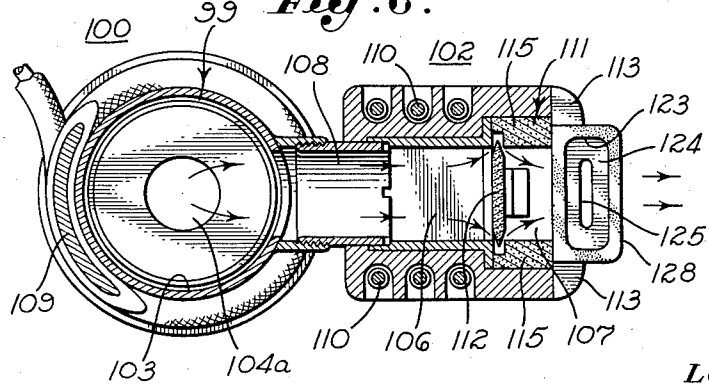


Fig. 6.



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2,717,962

ELECTRIC DISCHARGE DEVICES

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Application March 31, 1944, Serial No. 528,818

5 Claims. (Cl. 250—49.5)

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 electric discharge device including an improved electron source arrangement for producing an arc discharge that may be easily and simply regulated.

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

A further object of the invention is to provide a calutron ion source of improved construction and arrangement that is efficient in operation and subject to minimum wear and erosion.

A further object of the invention is to provide an arc discharge device with an improved electrode arrangement for increasing the life of the arc cathode.

In carrying out the objects of the present invention, a calutron ion source is provided with an improved electron source including a filamentary cathode, a plate-like arc cathode, and a control electrode arranged in alignment with the magnetic field of the calutron, the arc cathode being positioned immediately above a collimating electrode of the ion source arc chamber, which chamber contains a vapor through which an arc discharge is established. Heretofore, the electron source of the ion source unit of a calutron consisted of a directly heated cathode and entailed many disadvantages. Inasmuch as a low voltage and high current is required to bring the filamentary cathode to thermionic emission, regulation and adjustment thereof is difficult. Further, the physical configuration and position of such cathode exposes it to positive ion bombardment and rapid deterioration. With the improved arrangement, the filamentary cathode is shielded from positive ion bombardment by the plate-like arc cathode which can more easily withstand the positive ion bombardment and resulting deterioration. To operate the improved electron source the filamentary cathode is brought to thermionic emission, an adjustable potential is applied to the arc cathode with respect to the filamentary cathode and an adjustable bias is applied to the control electrode, which, if of proper geometry and disposition, will draw very little current. The adjustment and regulation of the improved electron source is both simple and efficient.

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 into which there may be incorporated an ion source embodying the present invention; Fig. 2 is a diagrammatic sectional view of the calutron taken along the line 2—2 in Fig. 1; Fig. 3 is a schematic perspective view of the electrode arrangement in a calutron ion source embodying the present invention; Fig. 4 is a longitudinal sectional view of a calutron ion source embodying the present invention; Fig. 5 is a front elevation view of the calutron ion source shown in Fig. 4; and Fig. 6 is a sectional view of the calutron ion source 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, 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 un-ionized vapor and for accelerating the segregated ions to relatively high velocities; electromagnetic means for deflecting the ions along curved paths, the radii of curvature of the paths of the ions being proportional to the square roots of the masses of the ions, whereby the ions are concentrated in accordance with their masses; and means for de-ionizing and collecting the ions of the selected isotope thus concentrated, thereby to produce a deposit of the element enriched with the selected isotope.

Referring now more particularly to Figs. 1 and 2 of the drawings, there is illustrated a representative example of a calutron 10 of the character noted, that 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 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 13 and are adapted to be removably secured in place, whereby the tank 13 is hermetically sealed. Also, vacuum pumping apparatus, not shown, 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 a 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, an upstanding 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 removal end wall 18 carries a filamentary cathode 25 adapted to be connected to a suitable source of filament suply, the filamentary cathode 25 overhanging the upper end of the arc-block 22 and arranged in alignment with respect to the upper end of the cavity formed therein. The arc-block 22 carries an anode 26 disposed adjacent the lower end thereof and arranged in alignment with respect to the cavity formed therein. Also, the arc-block 22 carries a collimating electrode 27 disposed adjacent the upper end thereof and having an elongated collimating slot 28 formed therethrough and arranged in alignment with respect to the filamentary cathode 25 as well as the anode 26 and the cavity formed in the arc-block 22. Both the anode 26 and the collimating electrode 27 are electrically connected to the source unit 20 which in turn is grounded; likewise, the tank 13 is grounded. Also, the filamentary cathode 25 and the cooperating anode 26 are adapted to be connected to a suitable source of arc supply. It should be noted that the above-described electrode arrangement is disclosed in the copending application of Oppenheimer, Serial No. 523,544, filed February 23, 1944.

Further, the removable end wall 18 carries ion accelerating structure 39 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 40 is formed in the ion accelerating structure 39 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 supply is adapted to be connected between the arc-block 22 and the ion accelerating structure 39, the positive and negative terminals of the supply mentioned being respectively connected to the arc-block 22 and to the ion accelerating structure 39. Further, the positive terminal of the ion accelerating potential is grounded.

The removable end wall 19 suitably supports a collector block 29 formed of stainless steel or the like and provided with two laterally spaced-apart cavities or pockets 30 and 31 which respectively communicate with aligned slots 32 and 33 formed in the wall of the collector block 29 disposed remote from the removable end wall 19. It is noted that the pockets 30 and 31 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 34 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 34 terminates adjacent the accelerating structure 39; and the other end of the tubular liner 34 terminates adjacent the collector block 29; the tubular liner 34 constituting an electrostatic shield for the high velocity ions traversing the curved paths between the slit 40 formed in the ion accelerating structure 39 and the slots 32 and 33 formed in the collector block 29, as explained more fully hereinafter. Finally, the tubular liner 34 is electrically connected to the ion accelerating structure 39 and to the collector block 29. Thus, it will be understood that the source unit 20 and the tank 13 are connected to the positive grounded terminal of the accelerating electrode supply; while the ion accelerating structure 39, the tubular liner 34 and the collector block 29 are connected to the ungrounded negative terminal of the accelerating electrode supply; the ion accelerating structure 39, the tubular liner 34 and the collector block 29 being electrically insulated from the component parts of the tank 13.

Considering now the general principle of operation of the calutron 10, 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, not shown, 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 circuit for the filamentary cathode 25 is closed, whereby the filamentary cathode is heated and rendered electron emissive. Then the electric circuit between the filamentary cathode 25 and the anode 26 is closed, whereby an arc discharge is struck therebetween, electrons proceeding from the filamentary cathode 25 through the collimating slot 28 formed in the collimating electrode 27 to the anode 26. The collimating slot 28 formed in the collimating electrode 27 defines the cross-section of the stream of electrons proceeding into the arc-block 22, whereby the arc discharge has a ribbon-like configuration and breaks 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. A more detailed explanation of the operation of the aforesaid arrangement may be had by referring to the copending application of Oppenheimer, Serial No. 523,544, filed Feb. 23, 1944.

The electric circuit between the arc-block 22 and the ion accelerating structure 39 is completed, the ion accelerating structure 39 being at a high negative potential with respect to the arc-block 22, whereby the positive ions in the arc-block 22 are attracted by the ion accelerating structure 39 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 39 and the adjacent wall of the arc-block 22, and thence through the slit 40 formed in the ion accelerating structure 39 into the interior of the tubular liner 34. 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 40 into the tubular liner 34.

As previously noted, the collector block 29, as well as the tubular liner 34, is electrically connected to the ion accelerating structure 39, whereby there is an electric-field-free path for the high-velocity positive ions disposed between the ion accelerating structure 39 and the collector block 29 within the tubular liner 34. The high-velocity positive ions entering the adjacent end of the liner 34 are deflected from their normal straight-line path and from a vertical plane passing through the slot 24 and the aligned slit 40, due to the effect of the relatively strong magnetic field maintained through the space within the tank 13 and the liner 34 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 the relatively light isotope of the elements describe an interior arc of relatively short radius and are focused through the slot 32 into the pocket 30 formed in the collector block 29; whereas ions of the relatively heavy isotope of the element describe an exterior arc of relatively long radius and are focused through the slot 33 into the pocket 31 formed in the collector block 29. Accordingly, the relatively light ions are collected in the pocket 30 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 **31** 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 **30** and **31** of the collector block **29**, the end wall **19** may be removed and the deposits of the collected isotopes in the pockets **30** and **31** in the collector block **29** 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 several isotopes of the element which 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 **30** of the collector block **29**, and uranium comprising principally U^{238} is collected in the pocket **31** of the collector block **29**. Also, it is noted that from a practical standpoint, the deposit of uranium collected in the pocket **30** of the collector block **29** 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 **30** of the collector block **29** 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 example the uranium deposited in the pocket **30** of the collector block **29** is considerably enriched, both with U^{234} and with U^{235}, and 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 **39**, through the liner **34**, toward the collector block **29**; 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 through the cavity in the arc-block **22** must 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.

While the source unit in the calutron disclosed in the previously mentioned copending application of Ernest O. Lawrence is satisfactory in operation, it does not possess the characteristics noted to the extent desired; nor has it the long life required for most efficient commercial operation.

Referring now more particularly to Fig. 3 of the drawings, the electrode arrangement in the calutron ion source unit **100** embodying the features of the present invention is illustrated schematically in perspective. More particularly, this ion source unit **100** comprises an electron source **101**, a plate-like collimating electrode **124** formed of tungsten, molybdenum, or the like, and a plate-like anode **127** formed of tungsten or the like. The electron source **101** and the electrodes **124** and **127** are arranged in alignment with 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 **53**.

Considering now the electron source **101**, there are provided a substantially U-shaped filamentary or first cathode **121** formed of tungsten or the like and arranged in a vertical plane parallel to the magnetic field, a plate-like arc cathode **117** formed of tungsten or the like and positioned above and adjacent to the collimating electrode **124**, and a plate-like control electrode **114** formed of tungsten or the like having a longitudinal slot **104** formed therein, the control electrode **114** being disposed between the filamentary cathode **121** and the arc cathode **117**. Further, it should be noted that the electrodes constituting the ion source unit **100** are all arranged in alignment with the magnetic field **53** of the calutron and that the electrodes **114**, **117**, **124** and **127** are disposed in planes normal to the magnetic field **53**. The longitudinal slot **104** formed in the control electrode **114** and a longitudinal slot **125** formed in the collimating electrode **124** are parallel one to the other. Moreover, it should be noted that the filamentary cathode **121** is disposed in a vertical plane and the longitudinal slot **104** formed in the control electrode **114** is of such configuration and is so positioned relative to the filamentary cathode **121** that the projection of the filamentary cathode along the magnetic field entirely passes through the longitudinal slot **104**.

Considering now the structure and dimensional details of the electrodes constituting the electron source **101** of the ion source unit **100**, highly satisfactory results have been obtained employing a filamentary cathode of circular cross-section having a diameter of 0.050″, the length of the central portion being slightly less than 0.750″. The control electrode **114** is disposed 0.020″ below the filamentary cathode **121** control electrode **114** and is of 0.060″ thickness, the longitudinal slot **104** formed in the electrode **114** being 0.750″ x 0.094″ and being aligned with the central portion of the filamentary cathode **121**, the width of the control electrode **114** being 1.000″. Further, the arc cathode **117** is of 0.0125″ thickness and is 0.875″ wide. The front edge of the arc cathode **117** extends about 0.094″ beyond the front edge of the longitudinal slot **104** formed in the control electrode **114**.

The filamentary cathode **121** is connected by way of an adjustable resistor **102***a* to a suitable source of filament supply indicated as a battery **103***a*; while the filamentary cathode **121** and the control electrode **114** are respectively connected by way of a potentiometer **130** to the terminals of a suitable source of control electrode supply. Further, the filamentary cathode **121** and the arc cathode **117** are respectively connected by way of a potentiometer **132** to the negative and positive terminals of a suitable source of cathode supply. The above connections constitute the electrical arrangement of the electron source **101** of the arc mechanism; whereas the arc cathode **117** and the anode **127** are respectively connected to the negative and positive terminals of a suitable source of arc supply, the collimating electrode also being electrically connected to the anode **127** thus completing the electric network of the ion source unit **100**.

Considering now the general principle of operation of the ion source unit **100** and more particularly the electron

source 101, the current flowing through the filamentary cathode 121 is adjusted by means of the adjustable resistor 102*a* until the filamentary cathode 121 becomes electron emissive. The cathode supply circuit is thence completed so that electrons emitted by the filamentary cathode 121 are accelerated to and bombard the arc cathode 117, thereby raising the temperature of the arc cathode 117 to incandescence and to electron emission. Thereafter, the control electrode supply circuit is completed thus applying a bias to the control electrode 114. It will be understood that by varying the potential of the cathode supply the energy with which the electrons leaving the filamentary cathode 121 bombard the arc cathode 117 may be regulated. Further, by varying the potential of the control electrode supply and consequently the impressed bias on the control electrode 114 with respect to the filamentary cathode 121 the number of electrons which are emitted by the filamentary cathode 121 and bombard the arc cathode 117 may be space charge controlled. Inasmuch as the filamentary cathode 121 is so positioned that its projection along the magnetic field passes through the longitudinal slot 104 of the control electrode 114, and since the electrons traveling from the filamentary cathode 121 to the arc cathode 117 are confined to paths aligned with the magnetic field, the control electrode current will be small even though a large positive bias is applied thereto. This feature is of great advantage since the current density of the electron stream bombarding the arc cathode 117 may be simply adjusted with a minimum dissipation of current. Consequently, the electron source arrangement 101 affords a variable source of electrons for an arc discharge of the ion source unit 100 which requires little additional apparatus of low current carrying capacity. Moreover, the electron emission of the arc cathode 117 may be also adjusted by varying the cathode supply voltage; but since the current output of the cathode supply is substantially high and the voltage swing necessary for a given change in the electron emission of the arc cathode 117 is greater than the voltage swing required on the control electrode 114, this method is not as facile as the method employing the control electrode. However either of these methods of control is easier than the previously used method of control by adjusting a large current in a directly heated cathode. Furthermore, inasmuch as the potential of the control electrode 114 relative to the arc cathode 117 is negative, the electrons emitted from the upper face of the arc cathode 117 will not bombard the control electrode 114.

The electrons emitted from the lower face of the arc cathode 117 are accelerated toward the collimating electrode 124, some of the electrons passing through the longitudinal slit 125 formed in the collimating electrode 124, which collimating slit defines the cross-section of the ionizing electron stream which is projected into the gaseous region between the collimating electrode 124 and the anode 127. The electrons thus projected into the gaseous region between the collimating electrode 124 and the anode 127 result in a discharge therethrough. This discharge through this region occurs between the arc cathode 117 and the anode 127 and is of the arc type, being characterized by a high current, a low voltage drop and a luminous plasma. Accordingly, there is defined a zone of intense ionization having a cross-section of the same shape as the longitudinal slit 125, this zone constituting part of the arc discharge between the arc cathode 117 and the anode 127. It should be noted that the aforesaid zone of intense ionization has a ribbon-like configuration and is believed to be a plasma region with little variation in potential.

Referring now more particularly to Figs. 4 to 6, inclusive, of the drawings, there are illustrated the structural details of the source unit 100 which is arranged in the magnetic field between the pole pieces of the calutron in the manner previously explained, the source unit 100 comprising a charge receptacle 99 and an arc-block 102. The charge receptacle 99 comprises wall structure, including a removable cover 101*a*, defining an upstanding cylindrical cavity 103 therein, that is adapted to receive a removable cylindrical charge bottle 104*a* containing a charge 105 which is to be vaporized. The arc-block 102 comprises wall structure defining an upstanding vapor distributing chamber 106 and an upstanding arc chamber 107 therein, the cavity 103 communicating with the vapor distributing chamber 106 through a tubular member 108 supported by the wall structure of the charge receptacle 99 and the wall structure of the arc-block 102. The wall structure of the charge receptacle 99 carries an exteriorly arranged electric heater 109 of any suitable form, whereby the charge receptacle 99 and consequently the charge bottle 104*a* may be appropriately heated in order to vaporize the charge 105 contained in the charge bottle 104*a*. Similarly, the wall structure of the arc-block 102 carries an exteriorly arranged electric heater 110 of any suitable form, whereby the arc-block 102, and more particularly the vapor distributing chamber 106 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 102 comprises a substantially inverted U-shaped frame member 111, supporting an upstanding baffle plate 112, the frame member 111 and the baffle plate 112 being formed of carbon or graphite. The frame member 111 is secured to the wall structure of the arc-block 102 by an arrangement comprising two upstanding strips 113, and comprises a top wall 128, two upstanding substantially parallel spaced-apart side walls 115 and a front wall 116, the front wall 116 having a centrally disposed longitudinal slot 117*a* formed therein and communicating with the arc chamber 107. The side edges of the baffle plate 112 are spaced a short distance from the side walls 115 of the frame member 111 in order to provide communication between the vapor distributing chamber 106 and the arc chamber 107, the baffle plate 112 defining the boundary between the chambers mentioned.

The wall structure of the charge receptacle 99 carries a standard 118 which supports cathode structure 119 in cooperating relationship with respect to the arc-block 102. More particularly, the cathode structure 119 comprises two terminals 120 supporting the opposite ends of the substantially U-shaped filamentary cathode 121, the opposite ends of the filamentary cathode 121 being removably clamped in place by the respective terminals 120, and the two terminals being connected to the source of filament supply, as previously noted. The control electrode 114 is disposed immediately below the filamentary cathode 121 and is connected by way of the lead 115*a* to a terminal of the control electrode supply, the other terminal of the control electrode supply being connected to the filamentary cathode 121. Further, the arc cathode 117 is positioned below the control electrode 114 and the cathode supply is applied between the filamentary cathode 121 and the arc cathode 117 as has been heretofore described. It should be noted that insulating members 129 are inserted between the terminals of the filamentary cathode 121 and the control electrode 114, and between the terminals of the control electrode 114 and the arc cathode 117.

The central portion of the top wall 128 of the frame member 111 has a transversely extending slot 122 formed therethrough communicating with the arc chamber 107. The upper end of the transverse slot 122 is provided with a counterrecess 123 extending thereabout which receives the collimating electrode 124, the collimating electrode 124 having the transversely extending slot 125 formed therethrough, as previously noted, and communicating with the transverse slot 122 formed in the top wall 128 and consequently with the arc chamber 107, the length of the slot 125 being greater than the width of the slot 117*a* formed in the front wall 116. More particularly, the arc cathode 117 is spaced a short distance above the collimating electrode 124; the filamentary cathode 121, the

transverse slot **104** formed in the control electrode **114** and the transverse slot **125** formed in the collimating electrode **124** being in vertical alignment. Further, a laterally extending slot **126** is formed in the front wall **116** of the frame member **111** adjacent the lower end thereof, and supports the anode **127** extending into the arc chamber **107** in vertical alignment with the transverse slot **125** formed in the collimating electrode **124**. The negative and positive terminals of the arc supply are respectively connected to the arc cathode **117** and to the arc-block **102**, the anode **127** and the collimating electrode **124** being connected together by the frame member **111**, and consequently by way of the arc-block **102** to the positive terminal of the arc supply mentioned, as previously noted.

Considering now the detailed operation of the source unit **100**, when the electric circuit for the heater **109** is completed, the charge receptacle **99** and consequently the charge bottle **104***a* are heated, whereby the charge **105** is vaporized, filling the cavity **103** in the charge receptacle **99**. The vapor passes through the tubular member **108** into the vapor distributing chamber **106**, whereby this chamber is filled with the vapor. The vapor is thoroughly diffused in the vapor distributing chamber **106** and passes around the side edges of the baffle plate **112** into the arc chamber **107**, whereby this chamber is filled with the vapor. More particularly, the arc chamber **107** is thoroughly and uniformly filled with the vapor to be ionized, due to the arrangement of the vapor distributing chamber **106** and the baffle plate **112**.

When the circuit for the filamentary cathode **121** is completed, the filamentary cathode **121** is heated and rendered electron emissive; and when the arc cathode circuit is completed between the filamentary cathode **121** and the arc cathode **117**, electrons are projected from the filamentary cathode **121** through the slot **104** formed in the control electrode **114** and bombard the arc cathode **117** thus rendering the arc cathode **117** electron emissive. Further, the control electrode supply circuit is closed and by varying the potential applied to the control electrode **114** the number of electrons bombarding the arc cathode **117** and consequently the electron emission thereof may be adjusted. Thereafter the arc supply circuit is closed and some of the electrons emitted by the arc cathode **117** are projected through the transverse slot **125** formed in the collimating electrode **124** into the arc chamber **107** and proceed toward the anode **127**. Accordingly, the collimating electrode **124** causes a stream of electrons having a ribbon-like configuration to be projected through the arc chamber **107**, whereby the vapor in the arc chamber **107** is ionized. Moreover, the width of the stream of electrons is greater than the width of the upstanding slot **117***a* formed in the front wall **116**, whereby any vapor flowing through the arc chamber **107** and the slot **117***a* must traverse the electron stream and thus be subjected to its ionizing influence. The positive ions produced in the arc chamber **107** are drawn through the upstanding slot **117***a* formed in the front wall **116** of the frame member **111** 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.

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 unit comprising means for establishing a magnetic field, a substantially U-shaped first cathode, a second cathode disposed transversely of said magnetic field with the discharge path between said cathodes aligned with said magnetic field, an anode mounted parallel to said second cathode with the path therebetween aligned with said magnetic field, a hollow arc-block defining a gaseous region therein positioned between said second cathode and said anode, means for rendering said first cathode electron emissive, means for applying a positive potential to said second cathode relative to said first cathode, whereby electrons emitted by said first cathode bombard said second cathode to raise said second cathode to an electron emissive temperature, a plate-shaped control electrode having an elongated slot with dimensions substantially equal to said first cathode disposed between said cathodes parallel to said first cathode, whereby the electron emission between said cathodes passes through the slot in said control electrode, means for applying a potential to said control electrode relative to said first cathode, whereby the electron emission between said cathodes may be controlled, means for applying a positive voltage to said anode with respect to said second cathode for establishing an arc therebetween, a plate-shaped collimating electrode having an elongated slot disposed transversely of said magnetic field between said second cathode and said anode, the slot of said collimating electrode being positioned parallel to the slot in said control electrode for defining the cross section of said arc, means for maintaining said collimating electrode at the potential of said anode, means for supplying gas to be ionized to said gaseous region, said arc-block having a slit in a wall thereof aligned with said magnetic field, and means for withdrawing a beam of ions from said gaseous region through said slit transversely of said magnetic field.

2. An electric discharge device comprising means for establishing a magnetic field, a substantially U-shaped filamentary cathode disposed in alignment with said magnetic field, a plate-shaped cathode disposed transversely of said magnetic field and spaced apart from said filamentary cathode with the path therebetween extending along said magnetic field, means for rendering said filamentary cathode electron emissive, a source of potential for rendering said plate-shaped cathode positive relative to said filamentary cathode, whereby electrons emitted by said filamentary cathode bombard said plate-shaped cathode to raise said plate-shaped cathode to an electron emissive temperature, a plate-shaped control electrode disposed transversely of said magnetic field between said cathode, said control electrode having an elongated slot extended parallel to and aligned with said filamentary cathode and having dimensions substantially equal to said filamentary cathode for defining the cross section of said electron emission between said cathodes, a source of potential connected between said filamentary cathode and said control electrode for controlling said electron emission between said cathodes, a plate-shaped anode disposed adjacent to and aligned with said plate-shaped cathode, a source of potential for rendering said anode positive relative to said plate-shaped cathode, whereby an arc discharge is established therebetween, and means for supplying a gas to be ionized between said plate-shaped cathode and said anode.

3. An electric discharge device comprising a vacuum envelope, a single gaseous region disposed therein, a filamentary cathode therein, and an anode therein, a second cathode therein disposed intermediate said filamentary cathode and said anode, means for rendering said filamentary cathode electron emissive, means for applying a positive potential to said second cathode relative to said filamentary cathode, whereby electrons emitted by said filamentary cathode create a nonplasma discharge that bombards said second cathode to raise said second cathode to an electron emissive temperature, a control electrode having an elongated slot formed therein positioned between said cathodes, said slot being disposed parallel to said filamentary cathode to limit the bombardment area of said second cathode, means for applying a potential to said control electrode relative to said filamentary cathode,

means for establishing a magnetic field along the discharge path between said cathodes, and means for producing an arc discharge in said gaseous region between said second cathode and said anode, said arc discharge being controlled by the potential of said control electrode.

4. In an ion source unit the combination comprising a hollow arc block defining a gaseous region and having an elongated exit slit in a front wall thereof, said slit being terminated at one end by an inwardly extended plate electrically conneted to said arc block and at the other end by a top wall of said arc block having a slot therein, said slot being disposed parallel to said front wall adjacent said slit and aligned with said plate, a substantially U-shaped first cathode disposed external of said arc block and parallel to said slot, a plate-shaped second cathode disposed parallel to said slotted top wall and between said slotted top wall and said first cathode, a plate-shaped control electrode having an elongated aperture disposed parallel to said second cathode and between said cathodes, first potential means connected between said cathodes for rendering said second cathode positive with respect to said first cathode, second potential means connected between said first cathode and said control electrode for controlling conduction therebetween, third potential means connected between said arc block and said second cathode for establishing an arc between said second cathode and said plate the configuration of the slot in said top wall, and means for establishing a magnetic field parallel to the paths between said cathodes and through said arc block.

5. In an ion source unit, the combination comprising a hollow arc block defining a gaseous region and having an elongated exit slit in a front wall thereof, said slit being terminated at one end by an inwardly extended plate electrically connected to said arc block and at the other end by a top wall of said arc block having a slot therein, said slot being disposed parallel to said front wall adjacent said slit and aligned with said plate, a substantially U-shaped first electron emissive cathode disposed external of said arc block and parallel to said slot, a plate-shaped electron emissive second cathode disposed parallel to said slotted top wall and between said slotted top wall and said first cathode, a plate-shaped control electrode having an elongated aperture disposed parallel to said second cathode and between said cathodes, first potential means connected between said cathodes for rendering said second cathode positive with respect to said first cathode, second potential means connected between said first cathode and said control electrode for controlling conduction therebetween, third potential means connected between said arc block and said second cathode for establishing an arc the length of said exit slit and having a cross section similar to the shape of the slot in said top wall, means for establishing a magnetic field through said arc block in the direction of said arc, means for introducing a gas to be ionized into said gaseous region, and means for withdrawing ions through said slit.

References Cited in the file of this patent

UNITED STATES PATENTS

1,419,547	Ehret	June 13, 1922
1,880,092	Hull	Sept. 27, 1932
2,009,457	Sloan	July 30, 1935
2,048,094	Applebaum	July 21, 1936
2,250,511	Varian	July 29, 1941
2,251,190	Kallmann	July 29, 1941
2,258,149	Schutze	Oct. 7, 1941
2,373,151	Taylor	Apr. 10, 1945