Aug. 2, 1955 B. F. MILLER 2,714,666

REGULATOR FOR CALUTRON ION SOURCE

Filed July 5, 1945

4 Sheets-Sheet 1

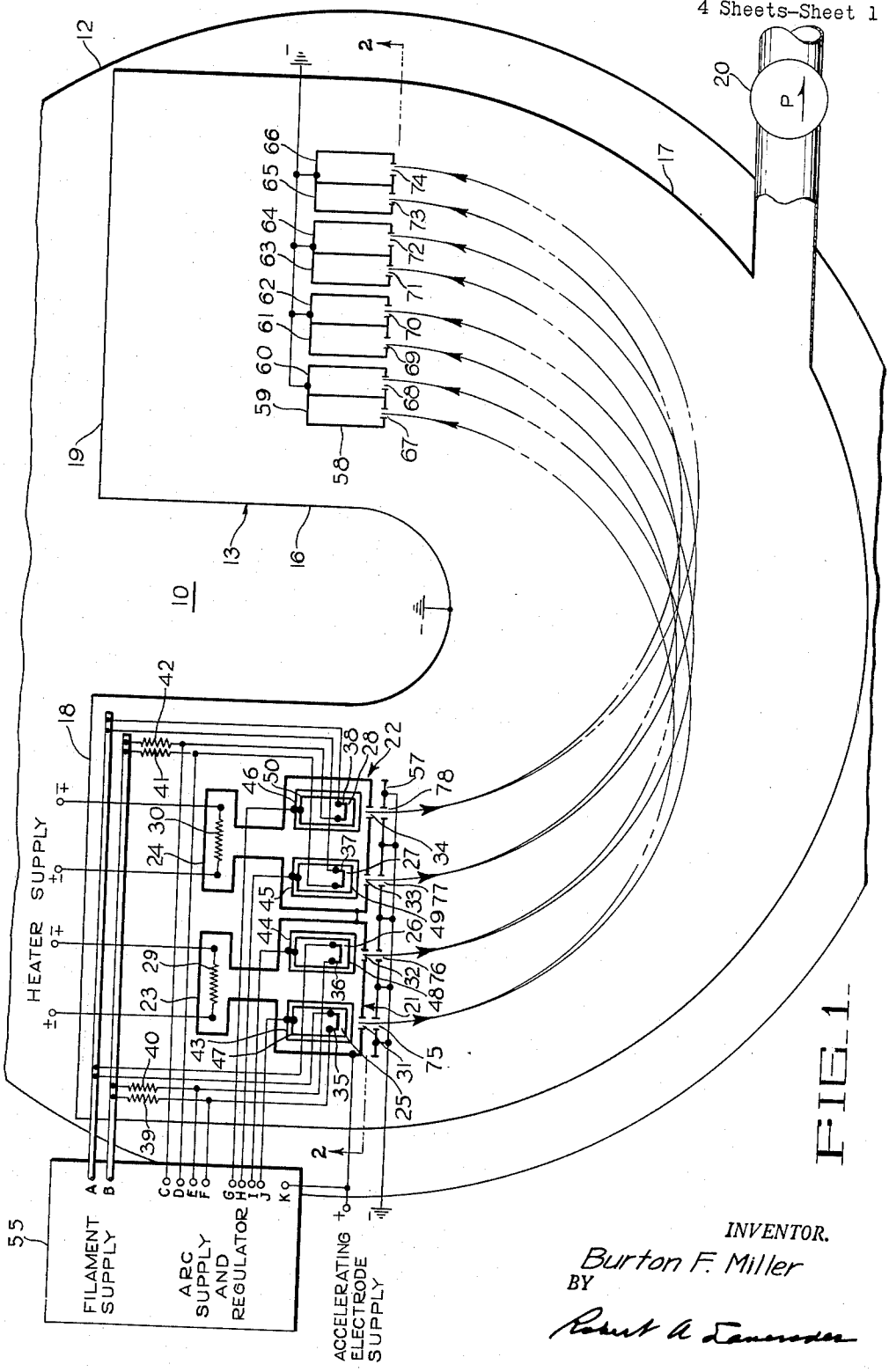


FIG. 1.

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REGULATOR FOR CALUTRON ION SOURCE

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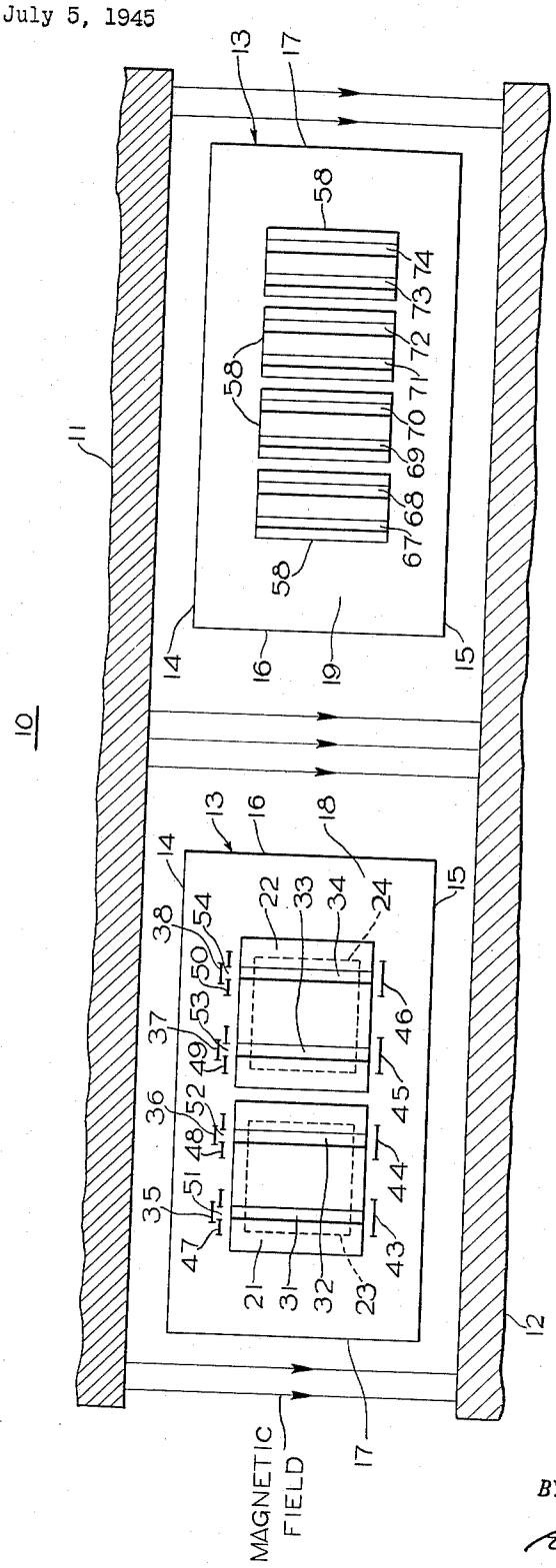


FIG. 2.

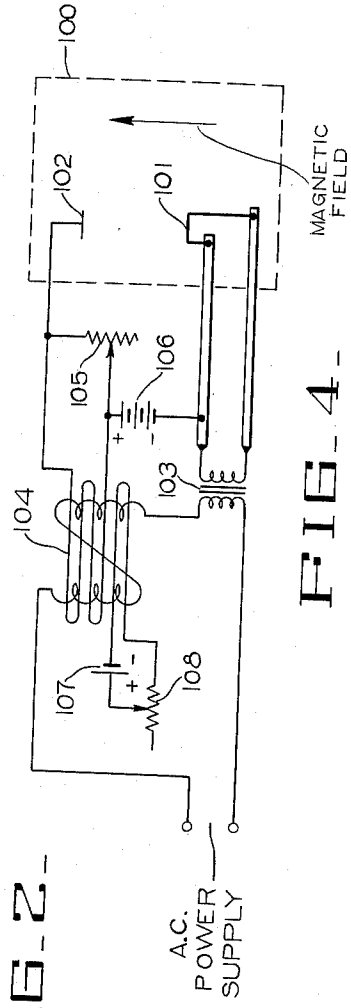


FIG. 4.

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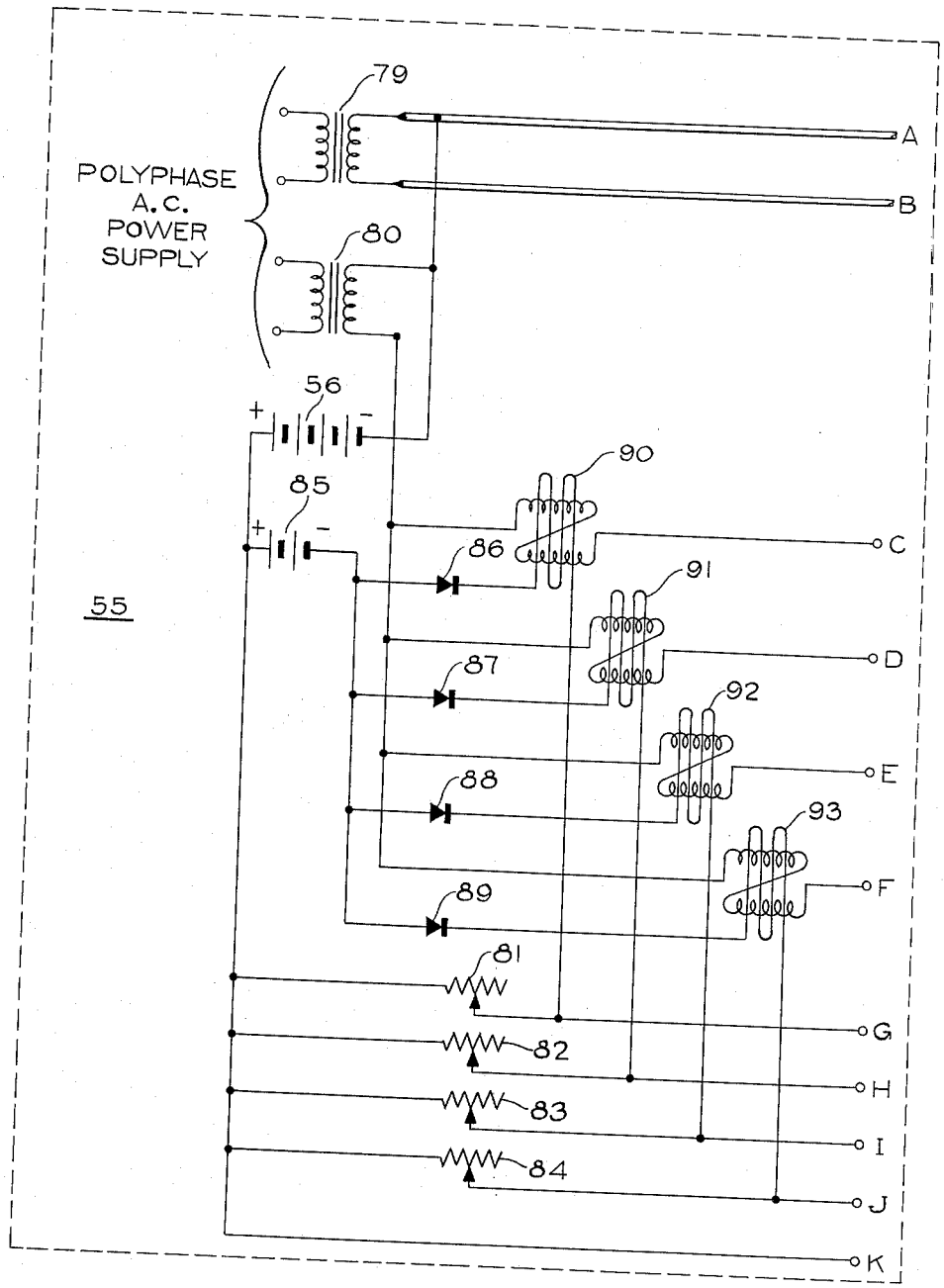


FIG. 3.

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REGULATOR FOR CALUTRON ION SOURCE

Filed July 5, 1945 4 Sheets-Sheet 4

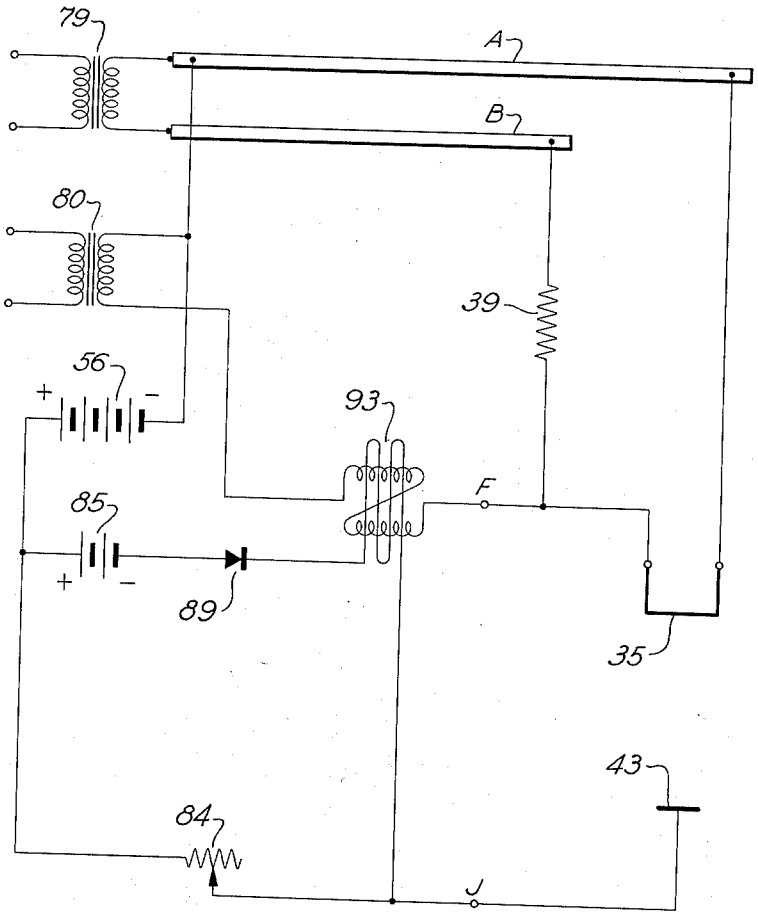


FIG_5_

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Patented Aug. 2, 1955

2,714,666

REGULATOR FOR CALUTRON ION SOURCE

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Application July 5, 1945, Serial No. 603,399

14 Claims. (Cl. 250—41.9)

This invention relates to improvements in electric discharge devices, and more particularly to calutrons of the type disclosed in the copending applications of Ernest O. Lawrence, Serial No. 557,784, filed October 9, 1944, and Serial No. 536,401, filed May 19, 1944.

A calutron is a device for increasing the proportion of a selected isotope in an element containing a plurality of isotopes in order to produce the element enriched with the selected isotope. Such a calutron essentially comprises means for vaporizing a quantity of material containing the element that is to be enriched with the selected isotope; means for subjecting the vapor to ionization, whereby at least a portion of the vapor is ionized, so that ions of the different isotopes are produced; electrical means for segregating the ions from the un-ionized vapor and for accelerating the segregated ions to relatively high velocities; magnetic 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 deionizing and collecting the ions of the selected isotope thus concentrated, thereby to produce a deposit of the element enriched with the selected isotope.

The apparatus is especially useful in producing uranium enriched with U^{235}.

In the previously-mentioned copending application, Serial No. 536,401, there is disclosed a calutron of the multiple beam type, including, as shown in Figures 24, 25, and 26 thereof, an ion source unit provided with an arc block having a number of arc chambers formed therein. In this source unit, each arc chamber is provided with electron emitting structure individual thereto which is utilized to ionize the vapor contained in the associated arc chamber.

Likewise, the instant application pertains to a calutron of the multiple beam type including an ion source unit provided with a plurality of arc blocks, each having one or more arc chambers formed therein. In this source unit, however, the electron emitting devices are provided with power supplies common to all of them, together with circuits adapted to regulating each individual arc. In another aspect, the conductors to two or more electron emitting devices may be combined electrically in such manner as to reduce the total number of heavy electrical conductors.

One object of this invention is to provide, in a calutron ion source unit, an improved cathode circuit and arc regulator arrangement.

Another object of the invention is to provide a regulated calutron multiple ion source unit requiring a reduced number of electrical conductors connected thereto.

Another object of the invention is to provide a calutron ion source apparatus employing a plurality of independently regulated ion generators.

Another object of the invention is to provide a calutron ion source unit including a plurality of cathodes

with an improved arrangement for controlling the emissions thereof.

Another object of the invention is to provide a calutron ion source unit with an improved circuit for regulating the arc current by utilizing a saturable reactor.

A further object of the invention is to provide a calutron ion source unit with an improved cathode circuit utilizing a polyphase source of power.

Further objects of the invention will appear from a reading of the following detailed description of apparatus embodying the invention.

In the accompanying drawings, forming part of the specification,

Figure 1 is a diagrammatic plan view of a calutron comprising an improved ion source employing a plurality of independently regulated ion generators;

Fig. 2 is a vertical sectional view of the calutron taken along the line 2—2 of Fig. 1;

Fig. 3 is a schematic wiring diagram of the ion source filament supply, arc supply and regulator incorporated in the calutron shown in Fig. 1;

Fig. 4 is a schematic wiring diagram of an alternate ion source filament supply, arc supply and regulator adapted to a calutron having a limited number of arcs, and

Fig. 5 is a wiring diagram of the embodiment of the invention shown in Figs. 1 and 3 and including circuits of a single ion generator for the purpose of simplifying the explanation of the operation of that embodiment.

Referring now more particularly to Figs. 1 and 2, there is illustrated a calutron 10 comprising magnetic field structure, including upper and lower pole pieces 11 and 12 provided with substantially 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 arcuate 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 20 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 ion source units 21 and 22 provided with charge receptacles 23 and 24, respectively. Two communicating arc blocks 25 and 26 are provided to the ion source unit 21 and likewise two communicating arc blocks 27 and 28 are provided to the ion source unit 22. An electric heater 29 is arranged in heat exchange relation with the charge receptacle 23 and is adapted to be connected to a suitable source of heater current supply, whereby the charge receptacle 23 may be appropriately heated, the charge receptacle 23 being formed of stainless steel or the like. Likewise electric heater 30 is arranged in heat exchange relationship with

charge receptacle 24. The arc blocks 25, 26, 27 and 28 are formed, at least partially, of brass or the like and have upstanding slots 31, 32, 33 and 34 formed in the front walls thereof remote from the charge receptacles 23 and 24. Thus, the arc blocks 25, 26, 27 and 28 are of hollow construction, the cavities in arc blocks 25 and 26 communicating with the interior of the charge receptacle 23 and the cavities in arc blocks 27 and 28 communicating with the interior of the charge receptacle 24.

Also, the removable end wall 18 carries four filamentary cathodes 35, 36, 37 and 38, each in series with its respective resistance element 39, 40, 41 or 42, and adapted to be connected through busses A and B to a suitable source of filament current supply. Alternating current is utilized to heat the cathodes and in this respect it is to be noted that the term "A. C." is taken to mean alternating current and "D. C." is taken to mean direct current in the remainder of the disclosure and in the appended claims. The series resistance elements 39, 40, 41 and 42 have electrical characteristics similar to those of the filamentary cathodes 35, 36, 37 and 38. Each filamentary cathode 35, 36, 37 and 38 overhangs the upper end of its respective arc block 25, 26, 27 and 28, and is arranged in alignment with respect to the upper end of the cavity formed therein. Each arc block 25, 26, 27 and 28 carries an anode 43, 44, 45 or 46, respectively, disposed adjacent the lower end thereof and arranged in alignment with respect to the cavity formed therein.

Also, each arc block 25, 26, 27 and 28 carries a collimating electrode 47, 48, 49 or 50, respectively, adjacent the upper end thereof, each having an elongated collimating slot 51, 52, 53 or 54, respectively, formed therethrough and arranged in alignment with the electron emitting portions of the respective one of the filamentary cathodes 35, 36, 37 or 38, as well as with the respective one of the anodes 43, 44, 45 or 46, and the respective one of the cavities formed in the arc blocks 25, 26, 27 or 28. The anodes 43, 44, 45 and 46 and the collimating electrodes 47, 48, 49 and 50 are electrically connceted to terminals J, I, H and G, respectively, of the arc supply and regulator apparatus 55. The positive terminal, K, of the arc supply and regulator apparatus 55 is associated with the positive terminal of a suitable source of accelerating electrode supply, as explained more fully hereinafter. On the other hand, the tank 13 is grounded. Also, the filament busses A and B are adapted to be operatively connected to the negative terminal of a suitable source of arc voltage supply 56, as shown in Fig. 3 and described more fully hereinafter.

Further, the removable end wall 18 carries an ion accelerating structure 57, formed at least partially of tungsten or the like, and disposed in spaced-apart relation with respect to the wall of the arc blocks 25, 26, 27 and 28 in which the slots 31, 32, 33 and 34 are formed. The source of accelerating electrode supply is adapted to be connected between the ion sources 21 and 22 and the ion accelerating structure 57, the positive and negative terminals of the supply mentioned being respectively connected to the ion sources 21 and 22 and to the ion accelerating structure 57. Further, the negative terminal of the ion accelerating electrode supply is grounded.

The removable end wall 19 suitably supports an ion collector assembly 58 formed of stainless steel or the like, and provided with pairs of laterally spaced-apart cavities or pockets 59, 60, 61, 62, 63, 64, 65 and 66 which respectively communicate with pairs of aligned slots 67, 68, 69, 70, 71, 72, 73 and 74 formed in the front wall of the ion collector assembly 58 disposed remote from the removable end wall 19. It is noted that the pockets 59, 61, 63 and 65 are adapted to receive one of the constituent isotopes of an element, and the pockets 60, 62, 64 and 66 another of the constituent isotopes, which have been separated in the calutron 10, as explained more fully hereinafter. Finally, the ion collector assembly 58 is electrically connected to the ion accelerating structure 57 and the grounded terminal of the accelerating electrode supply. Thus it will be understood that the ion source units 21 and 22 are connected to the positive ungrounded terminal of the accelerating electrode supply; while the tank 13, the ion accelerating structure 57 and the ion collector assembly 58 are connected to the negative grounded terminal of the accelerating electrode supply; the ion source units 21 and 22 being electrically insulated from the component parts of the tank 13. Thus the portion of the tank 13 disposed between the ion accelerating structure 57 and the ion collector assembly 58 constitutes an electrostatic shield for the high velocity ions traversing the curved paths between the slits 75, 76, 77 and 78 formed in the ion accelerating structure 57 and the slots 67, 68, 69, 70, 71, 72, 73 and 74 formed in the ion collector assembly 58, as explained more fully hereinafter.

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 receptacles 23 and 24, 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 20 associated with the tank 13 is initiated. When a pressure of the order of 10^{-5} to $^{-4}$ 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 energized and adjusted, whereby a predetermined magnetic field is established therebetween traversing the tank 13. The electric circuits for the heaters 29 and 30 are energized, whereby the charge in the charge receptacles 23 and 24 is heated and vaporized. The vapor fills the charge receptacles 23 and 24 and is conducted into the communicating cavities formed in the arc blocks 25, 26, 27 and 28. The polyphase A. C. power supply circuits are energized, whereby busses A and B are energized and the filamentary cathodes 35, 36, 37 and 38 are heated and rendered electron emissive. Then the arc voltage supply 56 causes an arc discharge to strike between the electron emitting portions of filamentary cathodes 35, 36, 37 and 38 and their respective anodes 43, 44, 45 and 46, with electron streams proceeding from the electron emitting portions of the filamentary cathodes 35, 36, 37 and 38, through the collimating slots 51, 52, 53 and 54, respectively, formed in the collimating electrodes 47, 48, 49 and 50, respectively, to the anodes 43, 44, 45 and 46, respectively. These electron streams may be controlled in intensity by means of the arc supply and regulator 55 and its controls as described hereinafter. The collimating slots 51, 52, 53 and 54 formed in the collimating electrodes 47, 48, 49 and 50, respectively, define the cross sections of the streams of electrons proceeding into the arc blocks 25, 26, 27 and 28, respectively, whereby each 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.

The electric circuit between the arc blocks 25, 26, 27 and 28 and the ion accelerating structure 57 is completed, the ion accelerating structure 57 being at a high negative potential with respect to the arc blocks 25, 26, 27 and 28, whereby the positive ions in the arc blocks 25, 26, 27 and 28 are attracted by the ion accelerating structure 57 and accelerated through the voltage impressed therebetween. More particularly, the positive ions proceed from the cavities formed in the arc blocks 25, 26, 27 and 28 through the slots 31, 32, 33 and 34 formed in the walls thereof, and across the space between the ion accelerating structure 57 and the adjacent walls of the arc blocks 25, 26, 27 and 28, and thence through the slits 75, 76, 77 and 78, respectively, formed in the ion accelerating structure 57. The high velocity positive ions

form four vertical upstanding ribbons or beams proceeding from the cavities formed in the arc blocks **25**, **26**, **27** and **28** through the four slots **31**, **32**, **33** and **34**, respectively, and the four aligned slits **75**, **76**, **77** and **78**, respectively.

As previously noted, the ion collector assembly **58**, as well as the tank **13**, is electrically connected to the ion accelerating structure **57**, whereby there is an electric-field-free path for the high velocity positive ions disposed between the ion accelerating structure **57** and the ion collector assembly **58** within the tank **13**. The high velocity positive ions are deflected from their normal straight-line path and from a vertical plane passing through the slots **31**, **32**, **33** and **34** and the aligned slits **75**, **76**, **77** and **78**, respectively, due to the effect of the relatively strong magnetic field maintained through the space within the tank **13** 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 element describe interior arcs of relatively short radius and are focused through the slots **67**, **69**, **71** and **73** into the pockets **59**, **61**, **63** and **65**, respectively, formed in the ion collector assembly **58**; whereas ions of the relatively heavy isotope of the element describe exterior arcs of relatively long radius and are focused through the slots **68**, **70**, **72** and **74** into pockets **60**, **62**, **64** and **66**, respectively, formed in the ion collector assembly **58**. Accordingly, the ions of the relatively light isotope of the element are collected in the pockets **59**, **61**, **63** and **65** and are de-ionized to produce a deposit of the relatively light isotope of the element therein; while the ions of the relatively heavy isotope of the element are collected in the pockets **60**, **62**, **64** and **66** 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 receptacles **23** and **24** 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 receptacles **23** and **24** 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 **59**, **60**, **61**, **62**, **63**, **64**, **65** and **66** of the ion collector assembly **58**, the end wall **19** is removed and the deposits of the collected isotopes in the pockets **59**, **60**, **61**, **62**, **63**, **64**, **65** and **66** in the ion collector assembly **58** are 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 one another, 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 previously-mentioned copending application, Serial No. 557,784, filed October 9, 1944, 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 receptacles **23** and **24** 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. In this case, uranium enriched with U^{235} is collected in the pockets **59**, **61**, **63** and **65** of the ion collector assembly **58**, and uranium comprising principally U^{238} is collected in the pockets **60**, **62**, **64** and **66** of the ion collector assembly **58**. Also, it is noted that from a practical standpoint, the deposit of uranium collected in the pockets **59**, **61**, **63** and **65** of the ion collector assembly **58** 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 pockets **59**, **61**, **63** and **65** of the ion collector assembly **58** 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 pockets **59**, **61**, **63** and **65** of the ion collector assembly **58** is considerably enriched, both with respect to U^{234} and U^{235}, and considerably impoverished with respect to U^{238}, as compared with natural or normal uranium.

Referring now to Fig. 3, the filament supply, arc supply and regulator **55** is shown together with the filament busses A and B and the terminals C, D, E, F, G, H, I, J and K. Suitable polyphase A. C. power is supplied to the transformers **79** and **80**. Voltage is supplied from the secondary of transformer **79** to the filament busses A and B. A suitable out-of-phase voltage is supplied from the secondary of transformer **80** to be used in a manner as hereinafter described. A suitable D. C. arc voltage supply **56** is connected between filament bus A and terminal K. The positive terminal of this arc voltage supply **56** also connects through arc current control rheostats **81**, **82**, **83** and **84** to terminals G, H, I and J, respectively. The positive terminal of the arc voltage supply **56** also connects to the positive terminal of a suitable D. C. bias voltage supply **85**. The negative terminal of this bias voltage supply connects to one side of a plurality of rectifiers **86**, **87**, **88** and **89**; each of which in turn is connected through the D. C. winding of a plurality of saturable reactors **90**, **91**, **92** and **93** respectively to the terminals G, H, I, and J respectively. Thus it is seen that any current which flows from the arc voltage supply **56** to the anodes **43**, **44**, and **45** and **46** of the calutron **10** must pass through either the arc current control rheostats **81**, **82**, **83** and **84**, respectively, or must pass through the bias voltage supply **85** and the rectifiers **86**, **87**, **88** and **89**, respectively, and the D. C. windings of the saturable reactors **90**, **91**, **92** and **93** respectively.

It is to be observed that the polarity of the bias voltage supply **85** is such as to prevent any current from flowing through the rectifiers **86**, **87**, **88** and **89** unless a sufficient voltage appears between terminal K and terminals G, H, I and J, respectively, to overcome the potential of the bias supply **85**. Should no current flow through rectifiers **86**, **87**, **88** and **89**, then no current will flow through the D. C. windings of the saturable reactors **90**, **91**, **92** and **93**, and the A. C. windings of saturable reactors **90**, **91**, **92** and **93** will have their maximum impedance. Under such conditions the voltage induced in the secondary of transformer **80** will cause a minimum of current to flow through the A. C. windings of saturable reactors **90**, **91**, **92** and **93** to the terminals C, D, E and F respectively and to the junction points between the filamentary cathodes **35**, **36**, **37** and **38**, respectively, and the resistors **39**, **40**, **41** and **42**, respectively, in series with the filamentary cathodes **35**, **36**, **37** and **38**, respectively. Further, since the impedance of the A. C. windings of the saturable reactors **90**, **91**, **92** and **93** is essentially that of an inductive reactance, any currents which flow in these circuits will tend to lag behind the applied voltages by approximately ninety electrical degrees. By arranging the secondary voltage of transformer **80** to have a leading vector relation with respect to the voltage developed between filament busses A and B connected to the secondary of transformer **79** it is possible to overcome the lagging phase relationship developed in the A. C. windings of saturable reactors **90**, **91**, **92** and **93** as hereinafter described. Such an electrical phase relationship may be obtained from two-phase input power whereby the voltage on the secondary of transformer **80** will lead

the voltage on the secondary of transformer 79 by ninety electrical degrees. Again, if three-phase input power is supplied, then the voltage on the secondary of transformer 80 will lead the voltage on the secondary of transformer 79 by one hundred and twenty electrical degrees.

The purpose of the filament supply, arc supply and regulator 55 is to produce and to regulate a plurality of electrical arc discharges between the thermally emissive portions of the filamentary cathodes 35, 36, 37 and 38 and their respective anodes 43, 44, 45 and 46. The purpose of these electrical arc discharges has already been described; this application deals with a method for regulating the current in each such electrical arc discharge.

Consider, for example, the ion generator comprising filamentary cathode 35, collimating electrode 47, and anode 43, as shown in Fig. 5. Collimating electrode 47 and anode 43 are electrically connected together and in turn are connected to terminal J. Any arc current which flows as a result of the electron emission of cathode 35 to the collimating electrode 47 or to the anode 43 must also flow through the arc current control rheostat 84 or its parallel circuit including the D. C. winding of saturable reactor 93, the rectifier 89, and the bias supply 85 as previously described. Now if the value of this arc discharge current is sufficiently low, the voltage drop developed across the arc current control rheostat 84 will be insufficient to overcome the bias voltage produced by the bias voltage supply 85 so that no current can flow through the D. C. winding of the saturable reactor 93 and the rectifier 89 in series. Under such conditions the impedance of the A. C. winding of the saturable reactor 93 will be a maximum and a minimum of current will flow through this A. C. winding. Further, under such conditions the currents flowing through the filamentary cathode 35 and its series resistor 39 will be essentially equal, since a minimum of current is being drawn through terminal F which leads to the junction between filamentary cathode 35 and series resistor 39. It is to be noted that transformer 79 produces a secondary voltage across busses A and B which appears across filamentary cathode 35 and its series resistor 39 in series. Further, because of the phase relationships developed by the secondary voltage of transformer 80 and the inductive reactance of the A. C. windings of saturable reactor 93, any current which flows through terminal F will be approximately in phase with the current flowing in bus A, thereby tending to reduce the current flowing in the filamentary cathode 35 to a value below the current flowing in the series resistor 39. However, as previously described, when no current is flowing through rectifier 89, no current will be flowing through the D. C. winding of saturable reactor 93, the impedance of the A. C. windings of saturable reactor 93 will be a maximum, the current through terminal F will be a minimum, and therefore the current flowing through the filamentary cathode 35 will be a maximum.

Under such conditions the filamentary cathode 35 will be heated to its maximum temperature by the current passing through it and will produce the maximum of thermally emitted electrons. These electrons will be attracted by the positive potentials of the collimating electrode 47 and the anode 43, which positive potential is produced by the arc voltage supply 56, and an electric arc discharge will result. Below a certain value of arc current, all of the arc current will pass through the arc current control rheostat 84, since the bias voltage supply 85 and the rectifier 89 combined to prevent any current from flowing through the D. C. winding of the saturable reactor 93 in the parallel circuit to the arc current control rheostat 84. However, when the arc current through terminal J reaches a predetermined value as determined by the setting of the arc current control rheostat 84, then the voltage drop developed across the arc current control rheostat 84 will exceed the voltage of the bias voltage supply 85 and current will begin to flow through the D. C. winding of the saturable reactor 93. As the current through the D. C. winding of saturable reactor 93 increases, the impedance of the A. C. winding of the saturable reactor 93 will decrease, thus allowing more A. C. current to flow through terminal F, causing less of the A. C. current flowing through series resistor 39 to flow through the filamentary cathode 35. This in turn will tend to reduce the thermal emission of filamentary cathode 35, and tend to reduce the arc current flowing through terminal J. Under such conditions a regulatory action is produced; that is, should for any reason the arc current rise above its desired predetermined value, the current through the filamentary cathode 35 would be reduced, thereby reducing its thermal emission and tending to maintain the arc current at its predetermined value. In such a circuit, relatively small currents flowing through terminal F with respect to the current flowing through the series resistor 39 can produce realtively large changes in the thermal emission of filamentary cathode 35 Thus, the conductor to terminal F will need to carry far less than the current in the filamentary cathode 35 which must be supplied from busses A and B.

It is to be noted that this arc discharge occurs in a region of concentrated magnetic field. For this reason, essentially all of the arc current flows between the filamentary cathode 35 and the collimating electrode 47 or between the filamentary cathode 35 and the anode 43. Essentially no arc current can flow between the filamentary cathode 35 and the arc block 25 because of the direction of this concentrated magnetic field.

The remaining circuits utilizing filamentary cathodes 36, 37 and 38 operate in exactly the same manner with the arc current controls 83, 82 and 81 respectively serving to determine the current in the arc discharge of each ion generator in the same manner as previously described.

All of the conductors previously described as connecting terminals of the filament supply, arc supply and regulator 55 to electrodes within the calutron tank 13 must of necessity pass through the walls of the calutron tank 13 at some point. Using these circuits as described, only two heavy current conductors, busses A and B, need to pass through the walls of the calutron tank 13, whereas all of the other conductors are relatively small current conductors. Thus, any number of ion generators could be utilized with only two heavy current conductors required. Further, although all of the ion generators obtain their power from common sources, it is possible to control the current of each arc discharge independently.

It is to be understood that the principles of the circuit shown in Fig. 3 can be applied not only to the calutron shown in Figs. 1 and 2, but also to other caultrons having various electrical and mechanical differences. Specifically, the circuit shown in Fig. 3 is not to be limited to any particular number of ion sources, such as the two ion source units 21 and 22, or to any particular number of filamentary cathodes and anodes, such as the four filamentary cathodes 35, 36, 37 and 38 and their four respective anodes 43, 44, 45 and 46, shown on Figs. 1 and 2. Rather, the advantages of the circuit shown on Fig. 3 are more marked with an increased number of regulated arcs.

Similarly, the circuit shown in Fig. 3 is not adversely affected by changes in the ion accelerating structure or in the accelerating electrode supply potentials. For example, the ion source units 21 and 22 could be operated at a grounded positive potential, with respect to the ion accelerating structure 57 and the ion collector assembly 58 operated at a negative ungrounded potential.

Referring now to Fig. 4, an alternate electrical circuit is shown which is particularly advantageous for calutrons wherein a limited number of ion generators are to be utilized. The calutron ion generator 100 includes filamentary cathode 101 and anode 102, arranged in a con-

centrated magnetic field. Although calutron ion generator **100** shows schematically only two electrodes, filamentary cathode **101** and anode **102**, it is to be understood that Fig. 4 refers to these certain portions of a complete calutron generally similar to that one shown on Figs. 1 and 2. Voltage for the filamentary cathode **101** is obtained from the secondary of transformer **103**. Primary voltage for transformer **103** is obtained from a suitable A. C. power source through the A. C. windings of saturable reactor **104**.

The anode **102** connects both to the D. C. control winding of the saturable reactor **104** and to the arc current control rheostat **105** in parallel and thence to the positive terminal of a suitable arc voltage supply **106**. The negative terminal of the arc voltage supply **106** is connected to the secondary of transformer **103**.

The saturable reactor **104** also is equipped with a D. C. bias winding which is connected to a bias current supply **107** through a bias current control rheostat **108**. The combination of bias current supply **107** and bias current control rheostat **108** serves to produce the desired bias current through the D. C. bias winding of the saturable reactor **104** and this current is of such magnitude as to produce a high degree of saturation in the core of the reactor **104**.

The effect of this bias current is such as to reduce the impedance of the A. C. winding of the saturable reactor **104** to a desired low value. Thus, when the A. C. power supply is connected and current flows through the A. C. winding of saturable reactor **104** and through the primary winding of transformer **103** in series, there will be a relatively low voltage drop in the A. C. winding of the saturable reactor **104** because of the relatively low impedance in the A. C. winding of saturable reactor **104**, provided that no current flows in the D. C. control winding of saturable reactor **104**. This relatively large current flowing in the primary of transformer **103** will produce a relatively large voltage on the secondary of transformer **103** and will heat the filamentary cathode **101** to its thermally emissive temperature. The arc voltage supply **106** causes the anode **102** to assume a positive potential with respect to the filamentary cathode **101**. Under suitable conditions an arc discharge in a concentrated magnetic field will then occur between filamentary cathode **101** and anode **102**.

Any arc current which flows in the circuit of the anode **102** must flow either through the D. C. control winding of the saturable reactor **104** or through the arc current control rheostat **105**. Depending upon the setting of the arc current control rheostat **105**, a larger or a smaller portion of the arc current will flow through the D. C. control winding of the saturable reactor **104**.

The arrangement of the windings on the saturable reactor **104** is such that any increase in arc current through the D. C. control winding of saturable reactor **104** will produce a flux which will buck the flux produced by the D. C. bias winding of saturable reactor **104** and will thereby tend to reduce the net D. C. flux through the core of the saturable reactor **104**. When the current through the reactor D. C. control winding sets up a magnetomotive force sufficient to reduce the continuous flux through the reactor core below the threshold of saturation the impedance of the A. C. winding of the saturable reactor will increase thereby reducing the current through the filamentary cathode **101**.

Thus, with an increase of arc current the impedance in series with the primary of transformer **103** will be increased and the secondary voltage of transformer **103** will be decreased, reducing the temperature of filamentary cathode **101**, reducing its thermal emission, and tending to return the arc current to its previous value. The amount of arc current can be determined by the setting of the arc current control rheostat **105**. In other words, this circuit produces a regulatory effect which tends to maintain the arc current constant at a predetermined value.

It is to be understood that the circuit shown in Fig. 4 is to be preferred for one or a limited number of regulated arcs, while the circuit shown on Fig. 3 is to be preferred for a larger number of regulated arcs.

While there has been described what is at present considered to be the two preferred embodiments of the invention, it will be further 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. A regulator for a calutron ion source comprising in combination an ion source having an anode and a cathode, a resistor connected in series with said cathode, a pair of primary feeders for supplying heating current to said cathode through said resistor, a variable impedance device connected to the common terminal between said resistor and said cathode, a current supply connected in series with said variable impedance device across said cathode, said variable impedance device including control means connected between said anode and cathode and responsive to the current therebetween for controlling the impedance of said variable impedance device to maintain the arc current through said ion source substantially constant.

2. A regulator for a calutron ion source comprising in combination an ion source having an anode and a cathode, a resistor connected in series with said cathode, a pair of primary feeders for supplying heating current to said cathode through said resistor, a variable impedance device connected to the common terminal between said resistor and said cathode, a current supply connected across said cathode in series with said variable impedance device, means for producing a magnetic field aligned between said cathode and anode, and means responsive to the current between said anode and cathode for controlling the impedance of said variable impedance device to maintain the arc current through said ion source substantially constant.

3. A regulator for a calutron ion source comprising in combination an ion source having an anode and a cathode, wall structure for defining an arc chamber between said anode and said cathode, said arc chamber having an atmosphere to be ionized therein, a resistor connected in series with said cathode, a pair of primary feeders for supplying heating current to said cathode through said resistor, a variable impedance device connected to the common terminal between said resistor and said cathode, a current supply connected in series with said variable impedance device across said cathode, and means responsive to the current between said anode and cathode for controlling the impedance of said variable impedance device to maintain the arc current through said ion source substantially constant.

4. A regulator for a calutron ion source comprising in combination an ion source having an anode and a cathode, wall structure for defining an arc chamber between said anode and said cathode, said arc chamber having an atmosphere to be ionized therein, a resistor connected in series with said cathode, a pair of primary feeders for supplying heating current to said cathode through said resistor, a variable impedance device connected to the common terminal between said resistor and said cathode, a power supply connected in series with said variable impedance device across said cathode, means for producing a magnetic field aligned between said cathode and anode, and means responsive to the current between said anode and cathode for controlling the impedance of said variable impedance device to maintain the arc current through said ion source substantially constant.

5. A regulator for a calutron ion source comprising in combination an ion source having an anode and a cathode, a resistor connected in series with said cathode,

a pair of primary feeders connected to said cathode through said resistor, a variable impedance device connected to the common terminal between said resistor and said cathode and to the opposite side of said cathode, a source of current supply for said cathode connected to said pair of primary feeders, and means responsive to the current between said anode and cathode for controlling the impedance of said variable impedance device to maintain the arc current through said ion source substantially constant.

6. A regulator for a calutron ion source comprising in combination an ion source having an anode and a cathode, means for producing a magnetic field through said ion source parallel to the path between said anode and cathode, said ion source having an atmosphere to be ionized therein, a resistor, a pair of primary feeders for supplying heating current to said cathode through said resistor, a variable impedance device having an A. C. primary winding and a D. C. control winding, a current source connected through the primary winding of said variable impedance device across said cathode, and a source of arc current supply connected in series with said variable impedance control winding between said anode and said cathode thereby maintaining the arc current through said ion source substantially constant, said magnetic field substantially confining said arc current in an elongated zone in said ion source between said anode and said cathode.

7. A regulator for a calutron ion source comprising in combination an ion source having an anode and a cathode, a source of heating current connected to said cathode, a resistor connected in series between said heating current source and said cathode, a source of arc current supply connected between said cathode and said anode, a saturable reactor having a D. C. winding and an A. C. winding, said A. C. winding being connected from the resistor-cathode juncture to the opposite side of said cathode to control the heating current of said cathode over a predetermined range of values, said D. C. winding being connected in series with said arc current supply source, whereby the aforesaid arc current is maintained substantially constant through regulation of said cathode heating current.

8. A regulator for a calutron ion source comprising in combination an ion source having an anode and a cathode, means for producing a magnetic field aligned between said cathode and said anode, a resistor, a source of heating current connected to said cathode through said resistor, a source of arc current supply connected between said cathode and said anode, a saturable reactor having a D. C. winding and an A. C. winding, said A. C. winding being connected across said cathode to control the heating current of said cathode over a predetermined range of values, said D. C. winding being connected in series with said arc current supply source. whereby the aforesaid arc current is maintained substantially constant through regulation of said cathode heating current.

9. A regulator for a calutron ion source comprising in combination an ion source having an anode and a cathode, wall structure for defining an arc chamber between said anode and said cathode, said arc chamber having an atmosphere to be ionized therein, a source of heating current connected to said cathode, a source of arc current supply connected between said cathode and said anode, a saturable reactor having a D. C. winding and an A. C. winding, said A. C. winding being connected across said cathode to control the heating current of said cathode over a predetermined range of values, said D. C. winding being connected in series with said source of arc current supply, and an adjustable impedance connected across said D. C. winding for maintaining said D. C. winding responsive to a predetermined portion of the current between said anode and cathode, whereby the aforesaid arc current is maintained substantially constant through regulation of said cathode heating current.

10. A regulator for a calutron ion source comprising in combination an ion source having an anode and a cathode, a source of heating current connected to said cathode, a source of arc current supply connected between said cathode and said anode, a saturable reactor having a D. C. winding, a D. C. bias winding and an A. C. winding, a regulated source of unidirectional potential connected across said bias winding, said A. C. winding being connected in series between said heating current source and said cathode to control the heating current of said cathode over a predetermined range of values, said D. C. winding being connected in series with said source of arc current supply, whereby the aforesaid arc current is maintained substantially constant through regulation of said cathode heating current.

11. A regulator for a calutron ion source comprising in combination an ion source having an anode and a cathode, a resistor, a pair of primary feeders for supplying alternating heating current to said cathode through said resistor from one phase of a polyphase supply, a saturable reactor having a D. C. winding and an A. C. winding, one terminal of said A. C. winding being connected to the common terminal of said cathode and said resistor and the other terminal of said A. C. winding being connected in series with another phase of said polyphase supply to the other side of said cathode, and arc current supply, a second resistor, said second resistor being connected in series with said anode and the positive terminal of said arc current supply, the negative terminal of said arc current supply being connected to said cathode, a rectifier, a D. C. bias voltage supply connected in opposition to the polarity of said rectifier, said bias voltage supply and said rectifier and said D. C. winding being connected in series across said second resistor so that the arc current passing through said second resistor operates to control the heating current through said saturable reactor after said arc current reaches a value such that the voltage drop across said second resistor approximates the value of said D. C. bias voltage.

12. A regulator for a calutron ion source comprising in combination an ion source having an anode and a cathode, means for producing a magnetic field aligned between said cathode and said anode, a resistor, a pair of primary feeders for supplying alternating heating current to said cathode through said resistor from one phase of a polyphase supply, a saturable reactor having a D. C. winding and an A. C. winding, said A. C. winding being connected in series with another phase of said polyphase supply between the common terminal of said cathode and resistor and the other side of said cathode, an arc current supply, a second resistor, said second resistor being connected in series with said anode and the positive terminal of said arc current supply, the negative terminal of said arc current supply being connected to said cathode, a rectifier, a D. C. bias voltage supply connected in opposition to the polarity of said rectifier, said bias voltage supply and said rectifier and said D. C. winding being connected in series across said second resistor so that the arc current passing through said second resistor operates to control the alternating heating current through said saturable reactor after said arc current reaches a value such that the voltage drop across said second resistor approximates the value of said D. C. bias voltage.

13. A regulator for a calutron ion source comprising in combination an ion source having an anode and a cathode, wall structure for defining an arc chamber between said anode and said cathode, said arc chamber having an atmosphere to be ionized therein, a resistor, a pair of primary feeders for supplying alternating heating current to said cathode through said resistor from one phase of a polyphase supply, a saturable reactor having a D. C. winding and an A. C. winding, one terminal of said A. C. winding being connected to the common terminal of said cathode and said resistor and the other terminal

of said A. C. winding being connected through another phase of said polyphase supply to the other side of said cathode, an arc current supply, a second resistor, said second resistor being connected in series with said anode and the positive terminal of said arc current supply, the negative terminal of said arc current supply being connected to said cathode, a rectifier, a D. C. bias voltage supply connected in opposition to the polarity of said rectifier, said bias voltage supply and said rectifier and said D. C. winding being connected in series across said second resistor so that the arc current passing through said second resistor operates to control the current through said saturable reactor after said arc current reaches a value such that the voltage drop across said second resistor approximates the value of said D. C. bias voltage.

14. A regulator for an ion source comprising in combination an ion source having an anode and a cathode, means establishing a magnetic field through said ion source parallel to the path between said cathode and anode, said ion source containing an atmosphere to be ionized, an arc

current circuit connected between said anode and cathode and including a source of unidirectional potential maintaining an arc discharge between said cathode and anode, a primary current source for supplying heating current to said cathode, a secondary current source, and a variable impedance connected across said cathode in series with said secondary current source, said variable impedance having control means integral therewith governed by the current of said arc current circuit to regulate the heating of said cathode in response to the magnitude of said arc discharge.

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