Sept. 2, 1958 B. F. MILLER 2,850,635

REGULATOR FOR CALUTRON ION SOURCE

Filed Aug. 28, 1945 4 Sheets-Sheet 1

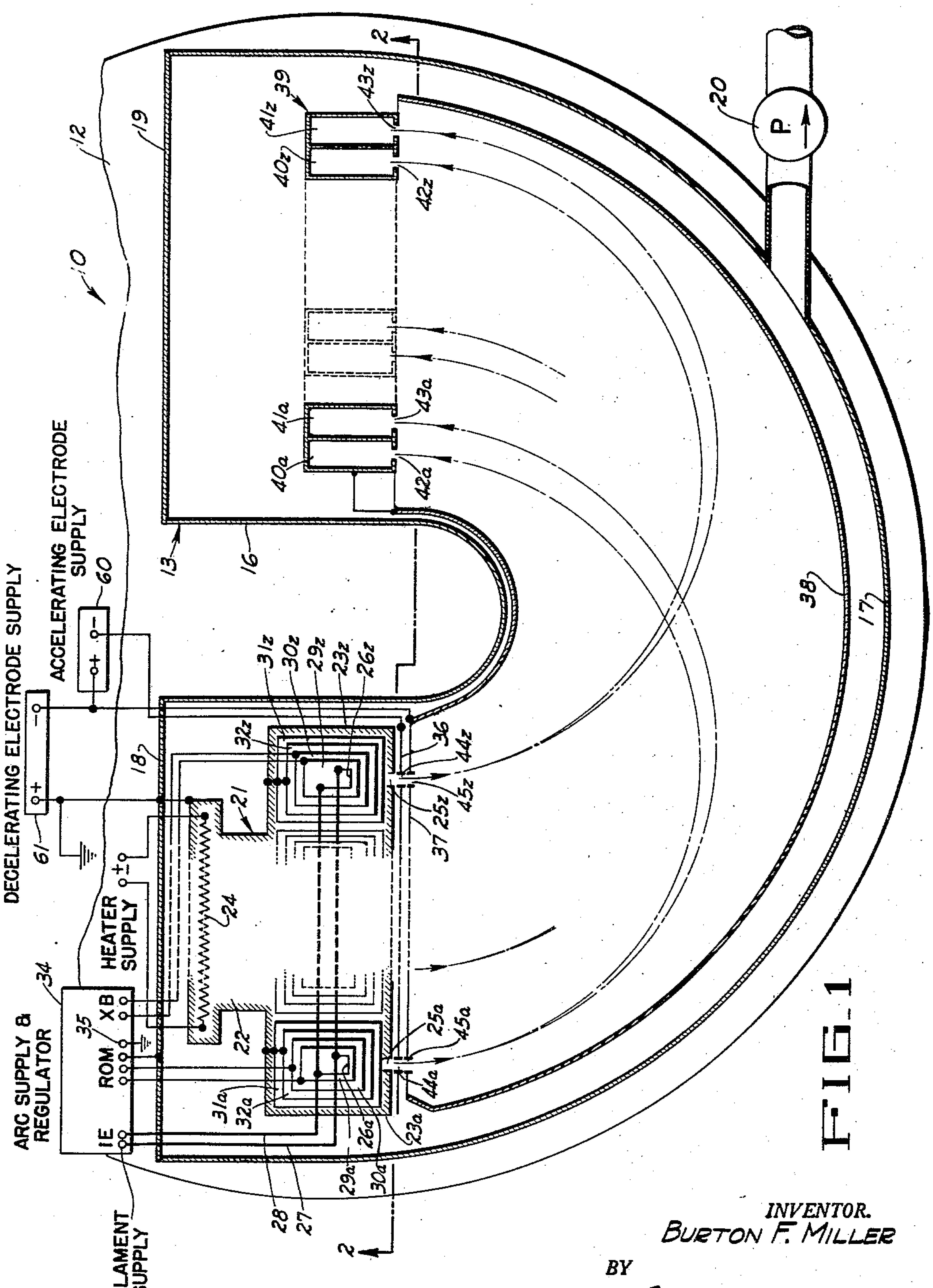

FIG. 1

INVENTOR.
BURTON F. MILLER

BY

Robert A. Lavender

Sept. 2, 1958 B. F. MILLER 2,850,635

REGULATOR FOR CALUTRON ION SOURCE

Filed Aug. 28, 1945 4 Sheets-Sheet 2

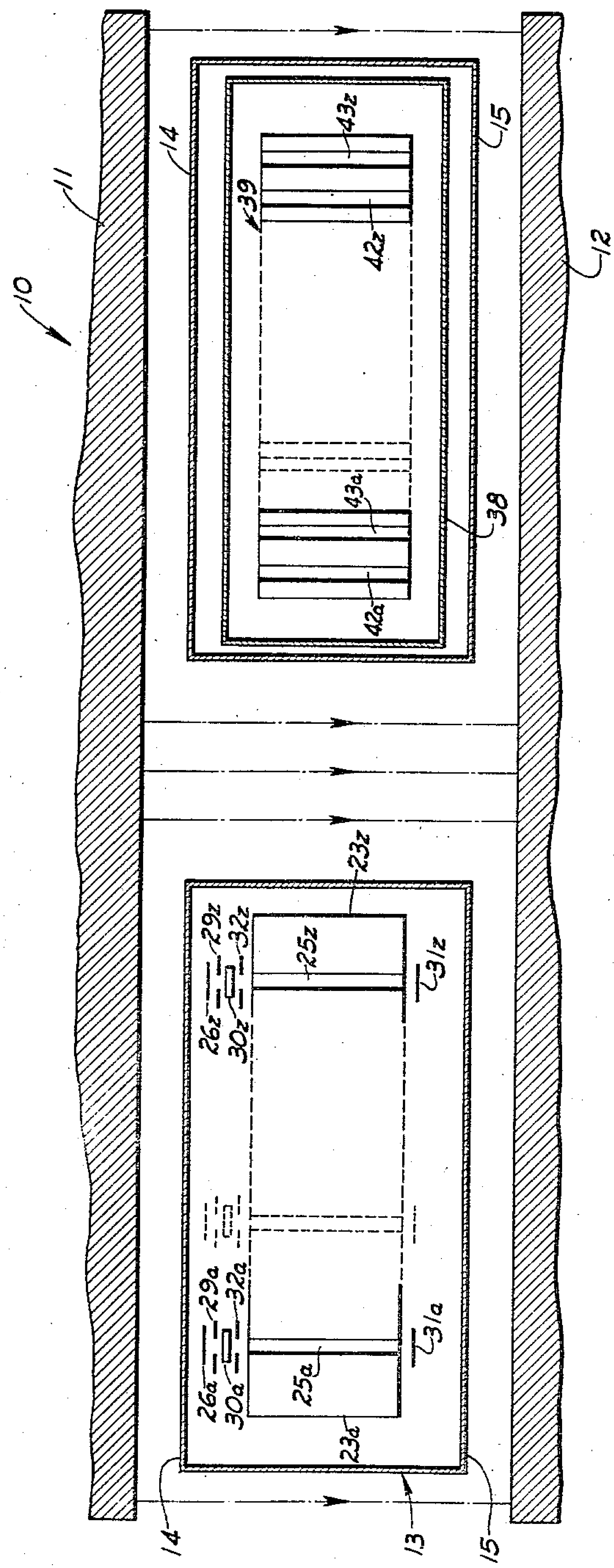

FIG. 2

INVENTOR.
BURTON F. MILLER
BY
ATTORNEY

Sept. 2, 1958 B. F. MILLER 2,850,635

REGULATOR FOR CALUTRON ION SOURCE

Filed Aug. 28, 1945 4 Sheets-Sheet 3

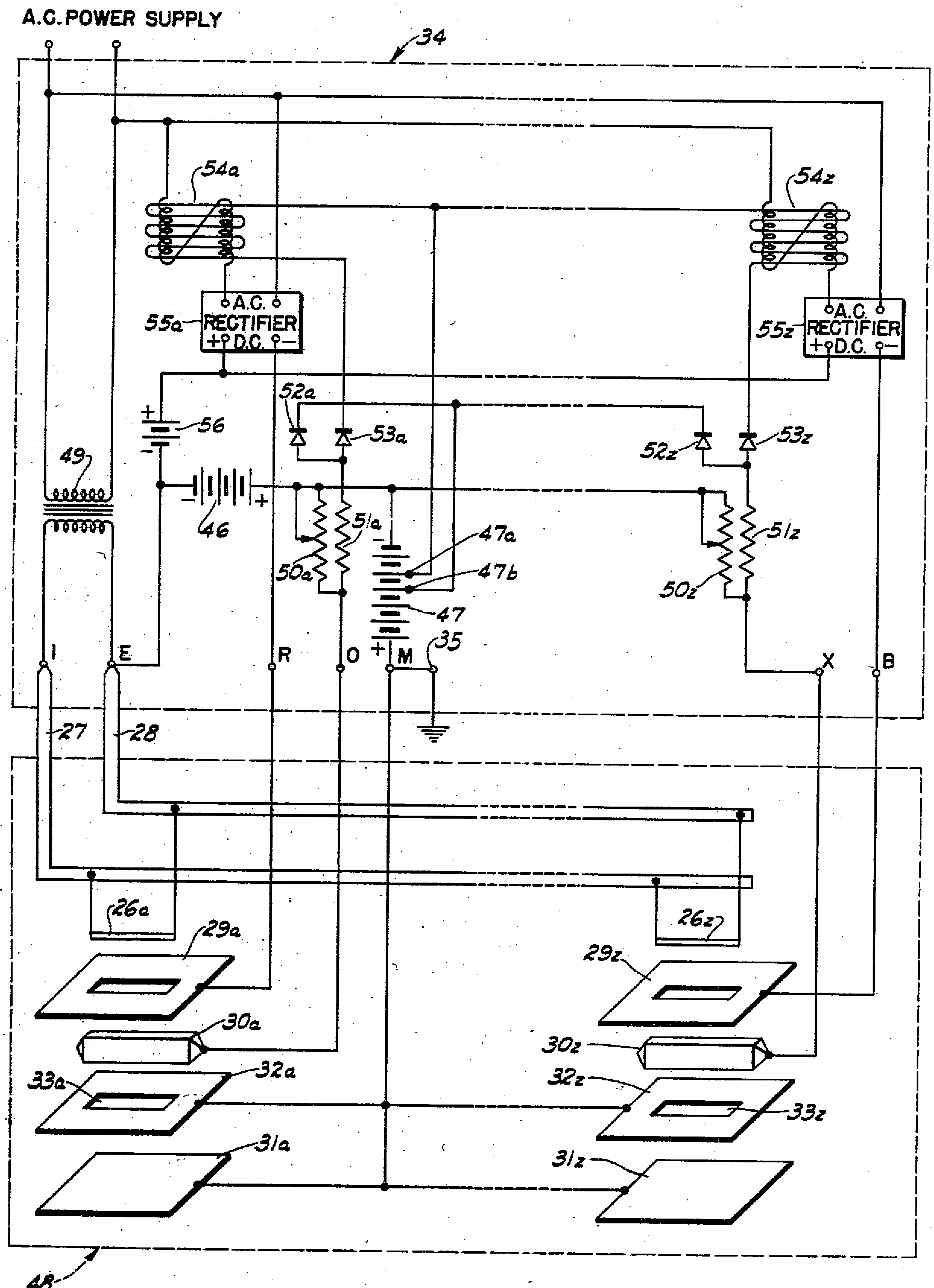

FIG_3

INVENTOR.
BURTON F. MILLER

BY Robert A. Lavender

ATTORNEY.

Sept. 2, 1958 B. F. MILLER 2,850,635

REGULATOR FOR CALUTRON ION SOURCE

Filed Aug. 28, 1945 4 Sheets-Sheet 4

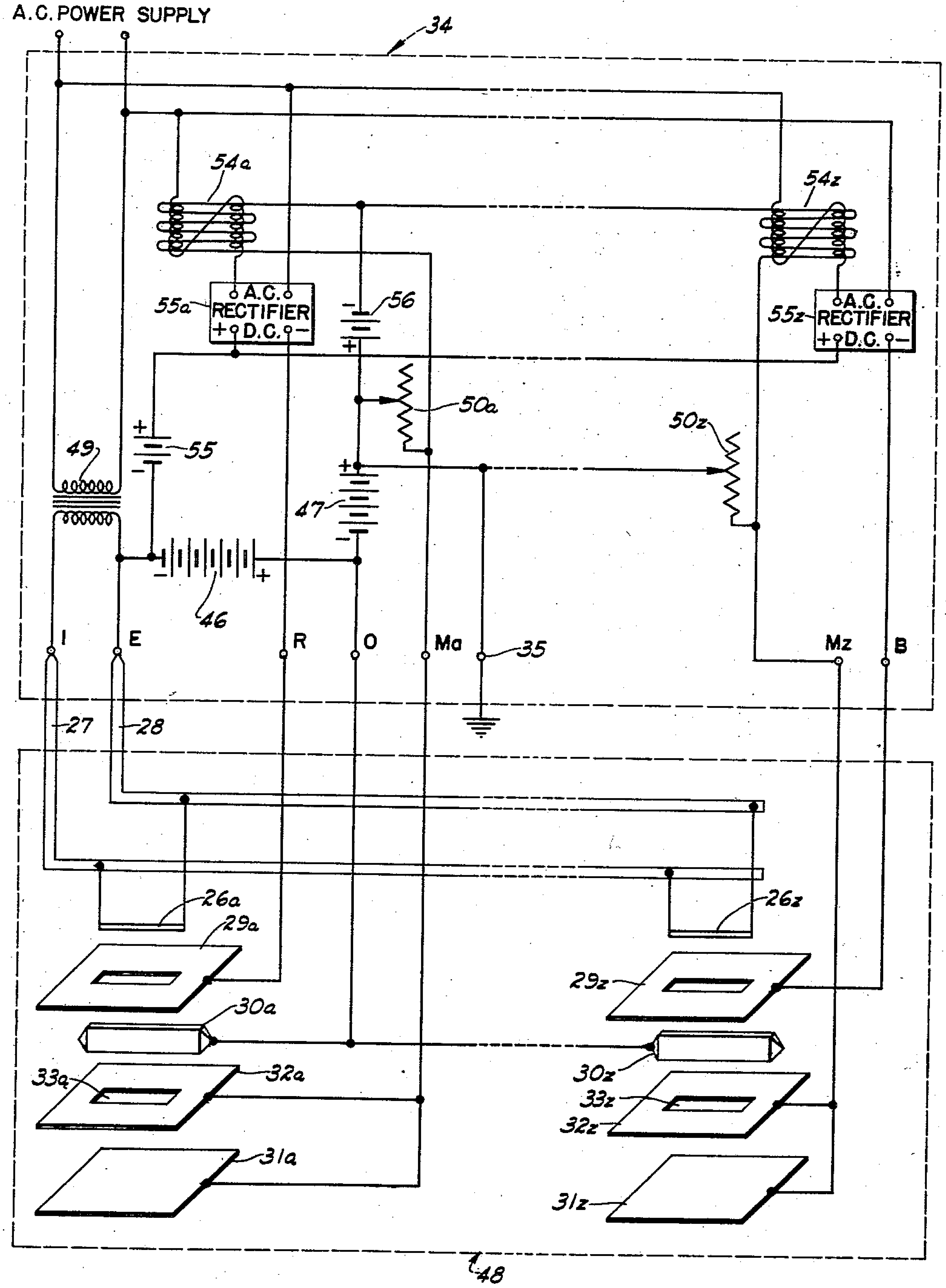

FIG_4

INVENTOR.
BURTON F. MILLER

BY Robert A. Lavender
ATTORNEY.

United States Patent Office

2,850,635

Patented Sept. 2, 1958

2,850,635

REGULATOR FOR CALUTRON ION SOURCE

Burton F. Miller, Berkeley, Calif., assignor to the United States of America as represented by the United States Atomic Energy Commission

Application August 28, 1945, Serial No. 613,160

7 Claims. (Cl. 250—41.9)

This invention relates to improvements in electric discharge devices and circuit arrangements therefor, and more particularly to ion sources and circuit arrangements therefor as applied to calutrons of the type disclosed in the copending applications of Ernest O. Lawrence, Serial No. 557,784, filed October 9, 1944, now Patent No. 2,709,222 granted on May 24, 1955 and Serial No. 536,401, filed May 19, 1944, now Patent No. 2,714,644 granted August 2, 1955.

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 an arc chamber 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 for 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 circuit utilizing an indirectly heated cathode.

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 the arc cathodes at a common potential.

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 the ion source unit **21** provided with a charge receptacle **22**. Communicating arc blocks **23**_a_, **23**_z_, are provided to the ion source unit **21**. An electric heater **24** is arranged in heat exchange relation with the charge receptacle **22** and is adapted to be connected to a suitable source of heater current supply, whereby the charge receptacle **22** may be appropriately heated, the charge receptacle **22** being formed of stainless steel or the like. The arc blocks **23**_a_, **23**_z_, are formed, at least partially, of brass or the like and have upstanding slots **25**_a_, **25**_z_, formed in the front walls thereof remote from the charge receptacle **22**. Thus, the arc blocks **23**_a_, **23**_z_, are of hollow construction, the cavities in arc blocks **23a**, **23z**, communicating with the interior of the charge receptacle **22**.

Also the removable end wall **18** carries filaments **26a**, **26z**, adapted to be connected through busses **27** and **28** to a suitable source of filament current supply. The filaments **26a**, **26z**, overhang the upper end of their respective arc blocks **23a**, **23z**, and are arranged in alignment with respect to the upper end of the cavity formed therein. Between the filaments **26a**, **26z**, and their respective arc blocks **23a**, **23z**, are arranged in alignment the respective control electrodes **29a**, **29z**, and the respective arc cathodes **30a**, **30z**. The arc blocks **23a**, **23z**, carry anodes **31a**, **31z**, respectively, disposed adjacent the lower end thereof and arranged in alignment with respect to the cavity formed therein.

Also, the arc blocks **23a**, **23z**, carry collimating electrodes **32a**, **32z**, respectively, adjacent the upper ends thereof, each of the collimating electrodes **32a**, **32z** having an elongated collimating slot **33a**, **33z**, respectively, formed therethrough and arranged in alignment with respect to the electron emitting portions of the arc cathodes **30a**, **30z**, respectively, as well as with the anodes **31a**, **31z**, respectively and the cavities formed in the arc blocks **23a**, **23z**, respectively.

The control electrodes **29a**, **29z**, the arc cathodes **30a**, **30z**, the collimating electrodes **32a**, **32z**, and the anodes **31a**, **31z**, are electrically connected to the arc supply and regulator apparatus **34**. The positive terminal **35** of the arc supply and regulator apparatus **34** is grounded and is thereby associated with the positive terminal of a suitable source of decelerating electrode supply, as explained more fully hereinafter. Also, the tank **13** is grounded. The filament busses **27** and **28** are adapted to be operatively connected to the arc supply and regulator apparatus **34**, as shown in Figs. 3 and 4 and described more fully hereinafter.

Further, the removable end wall **18** carries an ion accelerating structure **36**, formed at least partially of tungsten or the like, and disposed in spaced-apart relation with respect to the wall of the arc blocks **23a**, **23z**, in which the slots **25a**, **25z**, respectively, are formed. The negative terminal of the source **60** of accelerating electrode voltage supply is connected to the ion accelerating structure **36** and the positive terminal is connected to the ion decelerating structure **37** together with the negative terminal of the source **61** of the decelerating electrode voltage supply, the positive terminal of the latter source **61** being connected to the arc block **21** and also grounded.

The ion decelerating structure **37** is electrically connected to a tank liner **38**. Both the ion decelerating structure **37** and the tank liner **38** are suitably supported in and electrically insulated from the tank **13**. A suitable source of decelerating electrode voltage supply **61**, as mentioned above, is adapted to be connected with its positive terminal operatively associated with the ion source unit **21** and its negative terminal operatively associated with the ion decelerating structure **37** and the tank liner **38**.

The removable end wall **19** suitably supports an electrically insulated ion collector assembly **39** formed of stainless steel or the like, and provided with pairs of laterally spaced-apart cavities or pockets **40a** and **41a**, **40z** and **41z**, which respectively communicate with pairs of aligned slots **42a** and **43a**, **42z** and **43z**, formed in the wall of the collector block **39** disposed remote from the removable end wall **19**. It is noted that the pockets **40a**, **40z** are adapted to receive one of the constituent isotopes of an element, and the pockets **41a**, **41z** another of the constituent isotopes, which have been separated in the calutron **10**, as explained more fully hereinafter. Finally, the ion collector assembly **39** is electrically connected to the tank liner **38**, the ion decelerating structure **37**, and the ungrounded negative terminal of the decelerating electrode supply. Thus it will be understood that the ion source unit **21** and the tank **13** are connected to the positive grounded terminal of the decelerating electrode supply; while the ion decelerating structure **37**, the tank liner **38**, and the ion collector assembly **39** are connected to the negative ungrounded terminal of the decelerating electrode supply. This requires that the ion accelerating structure **36**, the ion decelerating structure **37**, the tank liner **38**, and the ion collector assembly **39** be electrically insulated from the component parts of the tank **13**. Thus the tank liner **38** disposed between the ion decelerating structure **37** and the ion collector assembly **39** constitutes an electrostatic shield for the high velocity ions traversing curved paths between the ion source unit **21** and the ion collector assembly **39**, as explained more fully hereinafter.

More specifically, the ions leave the ion source unit **21** through the slots **25a**, **25z** formed in the arc blocks **23a**, **23z**, pass through the slots **44a**, **44z** in the ion accelerating structure **36**, through the slots **45a**, **45z** in the ion decelerating structure **37**, through the space enclosed by the tank liner **38**, and enter the pockets **40a**, **40z** and **41a**, **41z** of the ion collector assembly **39** through the slits **42a**, **42z**, and **43a**, **43z**.

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 **22**, 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 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 energized and adjusted, whereby a predetermined magnetic field is established therebetween traversing the tank **13**. The electric circuit for the heater **24** is energized, whereby the charge in the charge receptacle **22** is heated and vaporized. The vapor fills the charge receptacle **22** and is conducted into the communicating cavities formed in the arc blocks **23a**, **23z**. The A. C. power supply circuit is energized, whereby busses **27** and **28** are energized and the filaments **26a**, **26z** are heated and rendered electron emissive.

The cathode bombardment voltage supply is operatively connected between the filamentary cathodes **26a**, **26z** and the arc cathodes **30a**, **30z** with the negative terminal of the cathode bombardment voltage supply associated with the filaments **26a**, **26z** and the positive terminal associated with the arc cathodes **30a**, **30z** as further described hereinafter. This bombardment voltage supply causes the electrons emitted from the electron emissive portions of the filaments **26a**, **26z** to be accelerated and bombard the arc cathodes **30a**, **30z**. The intensity of this bombardment can be controlled by the voltage of the control electrodes **29a**, **29z** as further described hereinafter.

This electron bombardment of the arc cathodes **30a**, **30z** raises their temperature to the thermionic emission point. An arc voltage supply is operatively connected between the arc cathodes **30a**, **30z** and the anodes **31a**, **31z**, with the negative terminal of the arc voltage supply associated with the arc cathodes **30a**, **30z** and the positive terminal associated with the anodes **31a**, **31z**.

This arc voltage supply causes an arc discharge to strike between the electron emitting portions of the arc cathodes **30a**, **30z** and their respective anodes **31a**, **31z**, with electron streams proceeding from the electron emitting portions of the arc cathodes **30a**, **30z** through the collimating slots **33a**, **33z** respectively formed in the collimating electrodes **32a**, **32z** respectively to the anodes **31a**, **31z** respectively. These electron streams may be controlled in intensity by means of the arc supply and regulator **34** and its controls as described hereinafter.

The collimating slots **33a**, **33z**, formed in the collimating electrodes 32a, 32z, respectively, define the cross sections of the streams of electrons proceeding into the arc blocks 23a, 23z, 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 23a, 23z, and the ion accelerating structure 36 is completed, the ion accelerating structure 36 being at a high negative potential with respect to the arc blocks 23a, 23z, whereby the positive ions in the arc blocks 23a, 23z are attracted by the ion accelerating structure 36 and accelerated through the voltage impressed therebetween.

The positive ions then come under the influence of the ion decelerating structure 37 and are decelerated thereby so as to reduce their velocity. In this manner the final velocity of the ions will depend upon the voltage of the decelerating electrode supply and will not depend upon the voltage of the accelerating electrode supply.

More particularly, the positive ions proceed from the cavities formed in the arc blocks 23a, 23z through the slots 25a, 25z formed in the walls thereof, across the space between the ion accelerating structure 36 and the adjacent walls of the arc blocks 23a, 23z through the slits 44a, 44z, respectively, formed in the ion accelerating structure 36, across the space between the ion decelerating structure 37 and the ion accelerating structure 36 and thence through the slits 45a, 45z in the ion decelerating structure 37.

The high velocity positive ions form vertical upstanding ribbons or beams proceeding from the cavities formed in the arc blocks 23a, 23z through the slots 25a, 25z, respectively, the aligned slits 44a, 44z, respectively, and the aligned slits 45a, 45z.

As previously noted the ion collector assembly 39 and the tank liner 38 are electrically connected to the ion decelerating structure 37, whereby there is an electric-field-free path for the high velocity positive ions disposed between the ion decelerating structure 37 and the ion collector assembly 39 within the tank liner 38. The high velocity positive ions are deflected from their normal straight-line path and from a vertical plane passing through the slots 25a, 25z and the aligned slits 45a, 45z, 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 42a, 42z into the pockets 40a, 40z, respectively, formed in the ion collector assembly 39; whereas ions of the relatively heavy isotope of the element describe exterior arcs of relatively long radius and are focused through the slots 43a, 43z into the pockets 41a, 41z, respectively, formed in the ion collector assembly 37. Accordingly, the ions of the relatively light isotope of the element are collected in the pockets 40a, 40z 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 41a, 41z 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 22 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 22 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 isotope of the element in the pockets 40a, 40z and 41a, 41z of the ion collector assembly 39, the end wall 19 is removed and the deposits of the collected isotopes in the pockets 40a, 40z and 41a, 41z in the ion collector assembly 39 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, now Patent No. 2,709,222 granted on May 24, 1955, 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 22 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 40a, 40z of the ion collector assembly 39 and uranium comprising principally U^{238} is collected in the pockets 41a, 41z of the ion collector assembly 39. Also, it is noted that from a practical standpoint, the deposit of uranium collected in the pockets 40a, 40z of the ion collector assembly 39 contains considerable amounts of U^{238}, in view of the fact that this isotope comprises the dominant constituent of normal uranium. Furthermore, the deposit of uranium collected in the pockets 40a, 40z of the ion collector assembly 39 contains a considerably increased amount of U^{234}, in view of the fact that it is not ordinarily feasible to separate U^{234} and U^{235} in the production of relatively large quantities of uranium enriched with U^{235} for commercial purposes. Accordingly, in this example the uranium deposited in the pockets 40a, 40z of the ion collector assembly 39 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 of the drawing in detail it will be observed that the terminals I, E, M, O, R, X, B shown in Fig. 3 connected to the schematically illustrated apparatus 34 correspond to similarly designated terminals used in the apparatus 34 illustrated in block form in Fig. 1. These terminals are connected to a pair of ion sources with the electrodes thereof shown in diagrammatic illustrations in the block designated by the reference numeral 48. The apparatus 34 may be designated as the filament supply, arc supply and regulator and includes the transformer 49 with the secondary thereof connected to the bus bars 27 and 28, which are connected to the ion generator filaments 26a, 26z so that these filaments are supplied with alternating current for the heating thereof. Only one pair of bus bars 27 and 28 is employed to supply heating current to a plurality of filaments. The bus bar 28 is connected to the negative terminals of the batteries 46 and 56, the positive terminal of the battery 46 being connected to the negative terminal of the battery 47 and the positive terminal of the battery 56 being connected to the positive terminals of the rectifiers 55a, 55z. The positive terminal of the battery 47 is connected to the calutron ground designated by reference numeral 35, to the ion generator anodes 31a, 31z and to the ion generator arc current collimating electrodes 32a, 32z. The positive terminal of the battery 46 and the negative terminal of the battery 47 are connected to the resistors 50a and 50z. These resistors are provided with variable contactors and function as arc current control rheostats for the arc currents of the ion generators. The other terminals of these arc current control resistors are connected to the bombardment cathodes 30*a*, 30*z*, respectively. These bombardment cathodes 30*a*, 30*z* are also connected to resistors 51*a*, 51*z*, respectively and through these to the rectifiers 53*a*, 53*z*, respectively, the negative terminals of the rectifiers 53*a*, 53*z* being connected to the D. C. control windings of the saturable reactors 54*a*, 54*z*, respectively. The other terminals of these D. C. control windings are connected together to the tap 47*a* of the battery 47. The A. C. windings of the saturable reactors 54*a*, 54*z* are connected in series with the A. C. inputs of the rectifiers 55*a*, 55*z*, respectively and these rectifiers are supplied from the A. C. power supply which also energizes the transformer 49. A pair of protective rectifiers 52*a*, 52*z* are connected around the rectifiers 53*a*, 53*z* and the control windings 54*a*, 54*z*, respectively to the terminal 47*b* of the battery 47, for the purpose of protecting the control windings of these saturable reactors from excessive D. C. control currents which may be fed to the control windings as a result of abnormal ion generator arc currents flowing through the resistors 50*a*, 50*z*, respectively.

Having set forth the physical connections of the ion generators and associated current supplies and controls, the operation of the apparatus shown in Fig. 3 will now be described.

Inasmuch as the battery 46 is connected with its negative terminal to the filament 26*a* and its positive terminal to the resistor 50*a* which, in turn, is connected to the bombardment cathode 30*a*, the bombardment current flowing from positive to negative will flow from the positive terminal of the battery 46 through the variable contactor associated with the resistor 50*a*, through the resistor 50*a*, thence to the bombardment cathode 30*a* and from the filament 26*a* through the filament busses 27 or 28 to the negative terminal of the battery 46. This bombardment current produces a potential drop across the used portion of the resistor 50*a*. The battery 47 supplying the arc current and being connected with its positive terminal to the arc anode 31*a* and its negative terminal to the resistor 50*a*, feeds the arc current from its positive terminal to the arc anode 31*a* and from the arc cathode 30*a* through the resistor 50*a* to the negative terminal of this battery. From the foregoing it is seen that the bombardment current flows through the resistor 50*a* in one direction and the arc current flows through this same resistor 50*a* in the opposite direction so that if these currents are not equal a net current will result with a corresponding potential drop across the resistor. If no arc current flows through the resistor 50*a* and only the bombardment current flows therethrough, then the resistor terminal connected to the positive terminal of the rectifier 53*a* will be negative and no current can flow through this rectifier and through the D. C. control winding of the saturable reactor 54*a*. However, if both bombardment current and arc current flow through the resistor 50*a* and the net current therethrough is that resulting from a larger arc current then the lower terminal of this resistor, that is, the terminal connected to the rectifier 53*a* through resistor 51*a* will assume a positive polarity. However, no current can flow through the rectifier 53*a* and the D. C. control winding of the saturable reactor 54*a* even when the proper polarity is applied to the rectifier from the potential drop across the resistor 50*a* unless this potential drop exceeds the potential of the battery 47 between the terminal 47*a* and the negative terminal of this battery since these potentials are in opposition to each other so far as the circuit of rectifier 53*a* and the control winding of the reactor 54*a* are concerned. Thus the control winding of the saturable reactor 54*a* does not exercise control of the reactance of this reactor unless the potential drop across the resistor 50*a* caused by the arc current exceeds a certain predetermined potential as outlined hereinbefore and this potential drop may be controlled by varying the tap of the resistor 50*a* manually so that different values of arc currents through this resistor may be used to exercise automatic control. When this predetermined potential is exceeded current will flow through the rectifier 53*a* and the control winding of the reactor 54*a* to reduce the inductance of the reactor 54*a* and thereby reduce the reactance of this reactor to alternating current so that the rectifier 55*a* has a greater A. C. potential applied thereto. As a result the D. C. output potential of this rectifier is increased and a higher negative potential is applied to the control grid 29*a* between the filament 26*a* and the bombardment cathode 30*a* and the current between this filament 26*a* and the bombardment cathode 30*a* is decreased. Consequently the emission of the bombardment cathode 30*a* is decreased, the arc current flowing to the anode 31*a* through the resistor 50*a* is decreased and the potential drop across this resistor 50*a* is decreased with the result that the D. C. control current through the rectifier 53*a* and the control winding of the saturable reactor 54*a* is decreased. Thereupon, the D. C. output voltage of the rectifier 55*a* is decreased and the apparatus through this operation adjusts itself automatically to substantially constant arc current for the purpose of ionizing the material fed into the ion generator apparatus between the bombardment cathode and the anode.

In the foregoing the operation of one of the ion generators only was taken up in detail and it will of course be apparent that the adidtional generator or generators and associated circuits will function in the same manner as the circuit described hereinbefore.

It will be observed that an auxiliary battery 56 is connected with its negative terminal to the negative terminal of the battery 46 supplying the cathode bombardment current. The positive terminal of this battery 56 is connected to the positive terminals of the D. C. outputs of the rectifiers 55*a*, 55*z*. This battery is not essential but is employed for the purpose of facilitating voltage adjustments and its polarity may be reversed if desired. Likewise the polarities of the rectifiers may be reversed and instead of applying a negative potential on the control grids 29*a*, 29*z* with respect to the filaments 26*a*, 26*z*, respectively, a positive potential may be applied thereto with respect to the filaments. The polarity applied to these grids with respect to the filaments depends upon, among other things, the size of the slot openings therein since it is obvious that the size of these openings will control the mu or amplification of the structure. In other words, if the slot opening is of a certain size it may be desirable to use a positive potential on the grid with respect to the filament whereas if this opening is larger than the aforesaid size it may be desirable to apply a negative potential on the grid with respect to the filament.

Another embodiment of this invention is shown schematically in Fig. 4 and it will be observed that here terminals I, E, Ma, Mz, O, R, B are provided to the apparatus 34 so that terminals Ma and Mz are employed instead of one terminal M of apparatus 34 in Fig. 3 and the functions of terminals O and X of Fig. 3 are consolidated into one terminal O in Fig. 4. The transformer 49 in this case also supplies the filament heating current to the filaments 26*a*, 26*z* through the bus bars 27 and 28. Likewise, a battery 46 having its negative terminal connected to the bus bar 28 is employed to supply the bombardment current between the bombardment cathodes 30*a*, 30*z* and the filaments 26*a*, 26*z*, respectively. The positive terminal of the battery 46 is connected to the negative terminal of the arc current supply battery 47 and the positive terminal of this battery 47 is connected to the anodes 31*a*, 31*z* and the collimating electrodes 32*a*, 32*z* through the arc current control rheostats 50*a*, 50*z*, respectively. Rectifiers 55*a*, 55*z* are connected with their negative output terminals to grid electrodes 29*a*, 29*z* respectively and with the positive output terminals together to the positive terminal of grid bias battery 55 to one side of the secondary of the filament transformer 49. The A. C. inputs of the rectifiers 55*a*, 55*z* are connected to the A. C. windings of the saturable reactors 54*a*, 54*z*, respectively. The

D. C. control windings of these saturable reactors **54***a*, **54***z* are connected with one terminal thereof to the ion generator anodes **31***a*, **31***z*, respectively, and the other terminals of these D. C. control windings are connected together to the negative terminal of the battery **56**, the positive terminal of this battery being connected to the calutron ground **35** and to the positive terminal of the battery **47**.

The operation of the apparatus shown in Fig. 4 is as follows:

The battery **46** supplies the bombardment current for the bombardment cathodes **30***a*, **30***z* and this bombardment current, of course, flows between these bombardment cathodes and the filaments **26***a*, **26***z*, respectively, through the grids **29***a*, **29***z*, respectively. The arc current which functions to ionize the material supplied to the ion generators flows between the anodes **31***a*, **31***z* and the respective bombardment cathodes **30***a*, **30***z* when these cathodes are heated by bombardment to be electron emissive. This arc current flows through the resistors **50***a*, **50***z* from the arc current supply **47** thereby producing IR drops across these resistors **50***a*, **50***z* depending of course upon the magnitudes of the resistors and the currents flowing therethrough.

The battery **55** which is connected with its negative terminal to the filaments **26***a*, **26***z* and with its positive terminal to the positive terminal of the rectifiers **55***a*, **55***z* provides a high positive bias to the grids **29***a*, **29***z* with respect to the filaments **26***a*, **26***z*, respectively, and these grids **29***a*, **29***z* are operated well in the saturation zone of the grid voltage-bombardment current characteristic so that substantial reductions in the positive grid voltages of the grids **29***a*, **29***z* is necessary before these grids exercise control of the bombardment current passing therethrough from the filaments **26***a*, **26***z* to the bombarded electrodes **30***a*, **30***z*, respectively. It will be observed that the polarity of the battery **55** is in opposition to the rectifiers **55***a*, **55***z* and, therefore, these rectifiers **55***a*, **55***z* may be used to vary the effective value of the voltage of the battery **55** on the grids **29***a*, **29***z*, respectively, as will be more fully described hereinafter. Since the D. C. control windings of the saturable reactors **54***a*, **54***z* are connected to the control rheostats **50***a*, **50***z*, respectively, the IR drops across these rheostats will be applied to the control windings of these saturable core reactors. When control currents flow through these D. C. windings the reactances of these reactors are decreased and therefore the alternating current potentials applied to the rectifiers **55***a*, **55***z* are individually increased so that the D. C. outputs of these rectifiers are increased thereby varying the potentials of the control grids **29***a*, **29***z*, respectively, with respect to the filaments **26***a*, **26***z*, respectively, in opposition to the grid bias battery **55**. The voltage of the battery **55** is sufficient to drive the grids **29***a*, **29***z* substantially positive with respect to their associated filaments so that a substantial reduction of the effective value of the potential of the battery **55**, by virtue of the increase in the output of the rectifier **55***a*, for control of grid **29***a* and rectifier **55***z* for control of grid **29***z*, is necessary before these grids are effective in decreasing the bombardment currents of the bombardment cathodes **30***a*, **30***z*, respectively. This is necessary so that a substantial arc current flows between the bombardment cathode and the anode of each ion generator before the respective grid electrodes start exercising control. When the grid electrodes start exercising control and reduce the bombardment cathode currents the temperatures of the bombardment cathodes **30***a*, **30***z* are decreased so that electron emissions from these bombardment cathodes are decreased and the arc current between the bombardment cathodes **30***a*, **30***z* and the anodes **31***a*, **31***z*, respectively, are decreased. Decreasing these arc currents produces lower potential drops across the control resistors **50***a*, **50***z*, respectively, so that control currents flowing through the D. C. windings of the reactors **54***a*, **54***z* are decreased and the A. C. potential applied to rectifiers **55***a*, **55***z* are caused to decrease since the reactances of the reactors are increased. In this manner the arc currents to the ion generators are stabilized around some predetermined values automatically.

It will be observed that the arc current control rheostats **50***a*, **50***z* may be manually adjusted if desired since the contactors thereof are variable and the arc currents of the ion generators may thereby be manually varied.

Furthermore, while from the foregoing description of the operation of the ion generators and associated circuits shown in Fig. 4 were set forth with respect to both ion generators shown, it is obvious that this control is individual and the arc current through one of the generators may be varied automatically independently of the automatic control of the arc current through the other.

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, a bombardment cathode, a grid and a filament, a pair of primary feeders for supplying heating current to said filament, a variable impedance device having a direct-current control winding and an alternating-current impedance winding, a rectifier having its output connected between said filament and said grid for supplying a bias potential to said grid with respect to said filament, a source of alternating current for said rectifier, said source of alternating current being connected to said rectifier through the alternating-current impedance winding of said impedance device, and means for supplying current to said direct-current control winding of said impedance device in accordance with the current supplied to said anode so that the bias potential of said grid is changed to decrease the bombardment current to said bombardment cathode when the anode current increases beyond a predetermined range.

2. A regulator for a calutron ion source comprising in combination an ion source having an anode, a bombardment cathode, a grid and a filament, a pair of primary feeders for supplying heating current to said filament, a variable impedance device having a direct-current control winding and an alternating-current impedance winding, a source of grid bias voltage for said grid for biasing said grid beyond saturation, a rectifier having its output connected between said filament and said grid for supplying negative bias potential to said grid with respect to said filament, a source of alternating-current for said rectifier, said source of alternating-current being connected to said rectifier through the alternating-current winding of said impedance device, and means for supplying current to said direct-current winding of said impedance device in accordance with the current supplied to said anode so that the negative bias of said grid is increased to decrease the effect of said source of grid bias potential and to decrease the bombardment current to said bombardment cathode when the anode current increases beyond a predetermined range.

3. A regulator for a calutron ion source comprising in combination an ion source having an anode, a bombardment cathode, a control electrode and a filament, wall structure for defining an arc chamber between said anode and said bombardment cathode, said arc chamber having an atmosphere to be ionized therein, a pair of primary feeders for supplying heating surrent to said filament, a rectifier for supplying a bias potential to said control electrode and being connected between said filament and said control electrode, a saturable reactor connected to control the output of said rectifier in accordance with the current to said anode to maintain said current sub-

stantially constant through the control of the bombardment current to said bombardment cathode from said filament.

4. A regulator for a calutron ion source comprising in combination an ion source having an anode, a bombardment cathode, a control electrode and a filament, wall structure for defining an arc chamber between said anode and said bombardment cathode, said arc chamber having an atmosphere to be ionized therein, a pair of primary feeders for supplying heating current to said filament, a rectifier for supplying a bias potential to said control electrode and being connected between said filament and said control electrode, a saturable reactor having a winding connected to the input of said rectifier and having another winding energized substantially in accordance with the current to said anode to control the bias of said control electrode to maintain said current substantially constant through the control of the bombardment current to said bombardment cathode from said filament.

5. A regulator for a calutron ion source comprising in combination an ion source having an anode, a bombardment cathode, a control electrode and a filament, said control electrode benig positioned between said filament and said bombardment cathode for controlling the bombardment of the cathode, wall structure for defining an arc chamber between said anode and said bombardment cathode, said arc chamber having an atmosphere to be ionized therein, a source of arc current supply connected between said bombardment cathode and said anode, a resistor connected in series with said arc current supply and said anode, a source-of-control-electrode-bias potential connected between said filament and said control electrode, a saturable reactor connected to control said source of control electrode bias potential, said saturable reactor having a direct-current control winding connected to be energized in accordance with the potential drop across said resistor to control the reactance of said saturable reactor for varying the bias to said control electrode.

6. A regulator for a calutron ion source comprising in combination an ion source having an anode, a bombardment cathode, a filament and a grid between said filament and said cathode, a source of bias voltage comprising a rectifier having its output connected between said grid and said filament, a saturable reactor having a direct-current control winding and an alternating-current impedance winding, said alternating-current impedance winding being connected in series with the input of said source of grid bias voltage, an arc current supply, a resistor connected in series with said cathode and the negative terminal of said arc current supply, the positive terminal of said arc current supply being connected to said anode, a direct-current bias voltage supply connected in opposition to the polarity of said rectifier, said direct-current control winding being connected to said resistor so that the arc current passing through said resistor operates to control the reactance of said saturable reactor.

7. A regulator for a calutron ion source comprising in combination an ion source having an anode, a bombardment cathode, a control electrode and a filament, said control electrode being positioned between said filament and said bombardment cathode for controlling the bombardment of the cathode, wall structure for defining an arc chamber between said anode and said bombardment cathode, said arc chamber having an atmosphere to be ionized therein, a source of arc current supply connected between said bombardment cathode and said anode, a source of bombardment cathode current supply, a resistor connected in series with said arc current supply and said cathode and in series with said bombardment cathode current supply and said cathode, a-source-of-control-electrode-bias potential connected between said filament and said control electrode, a saturable reactor connected to control said source of control electrode bias potential, said saturable reactor having a direct current control winding connected to be energized in accordance with the net potential drop across said resistor to control the reactance of said saturable reactor for varying the bias to said control electrode.

References Cited in the file of this patent

UNITED STATES PATENTS

1,628,678 Morrison ______________ May 17, 1927