Jan. 31, 1956 R. DE LIBAN 2,733,347

REGULATOR FOR CALUTRON ION SOURCE

Filed April 25, 1946 3 Sheets-Sheet 1

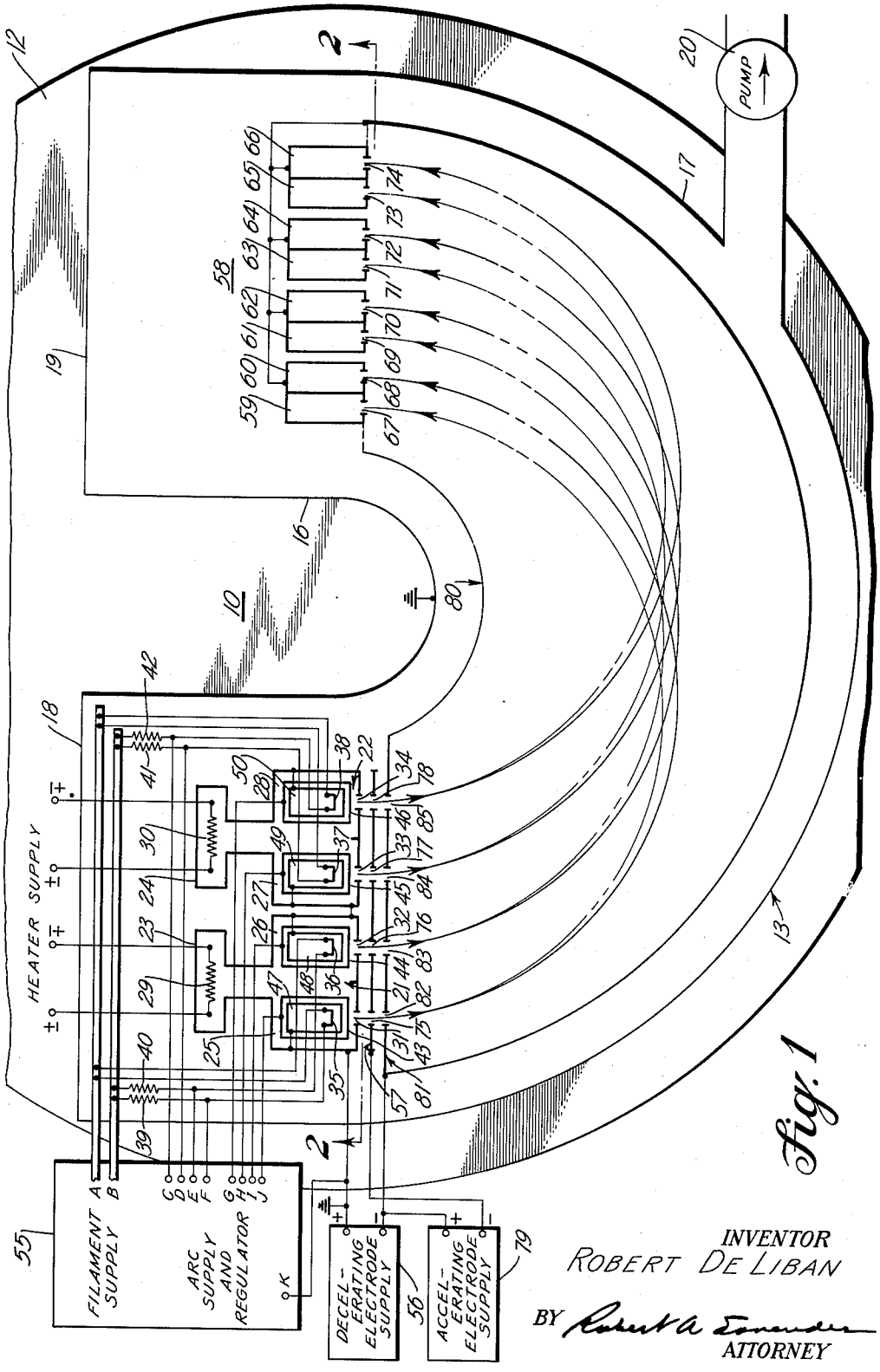


Fig. 1

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REGULATOR FOR CALUTRON ION SOURCE

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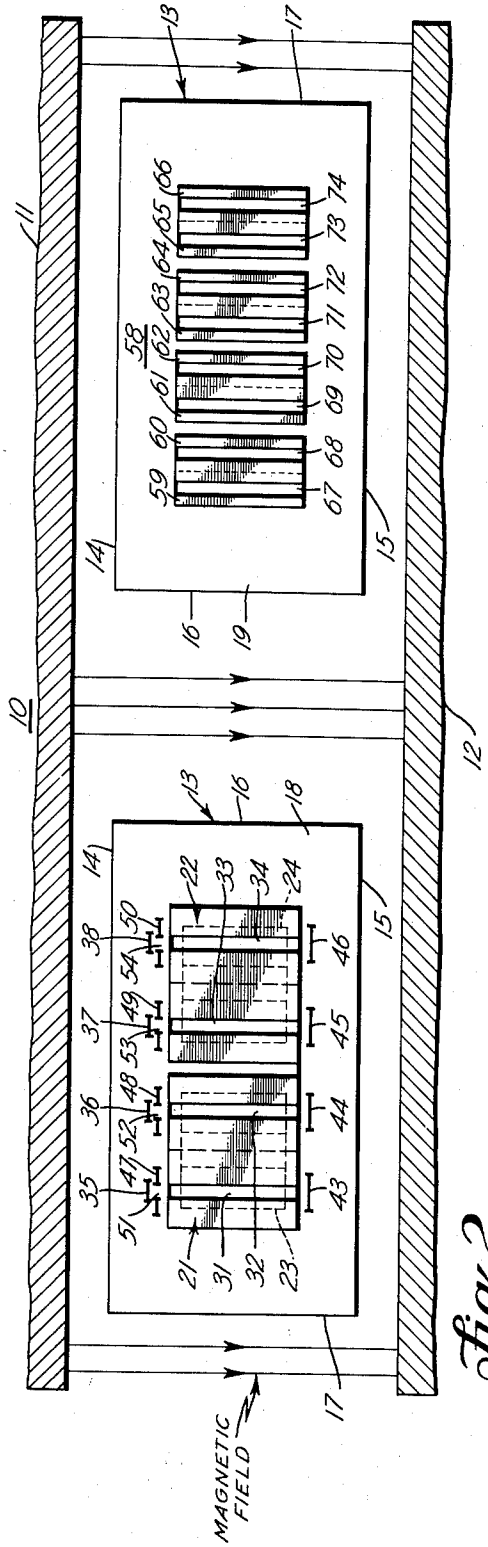


Fig. 2

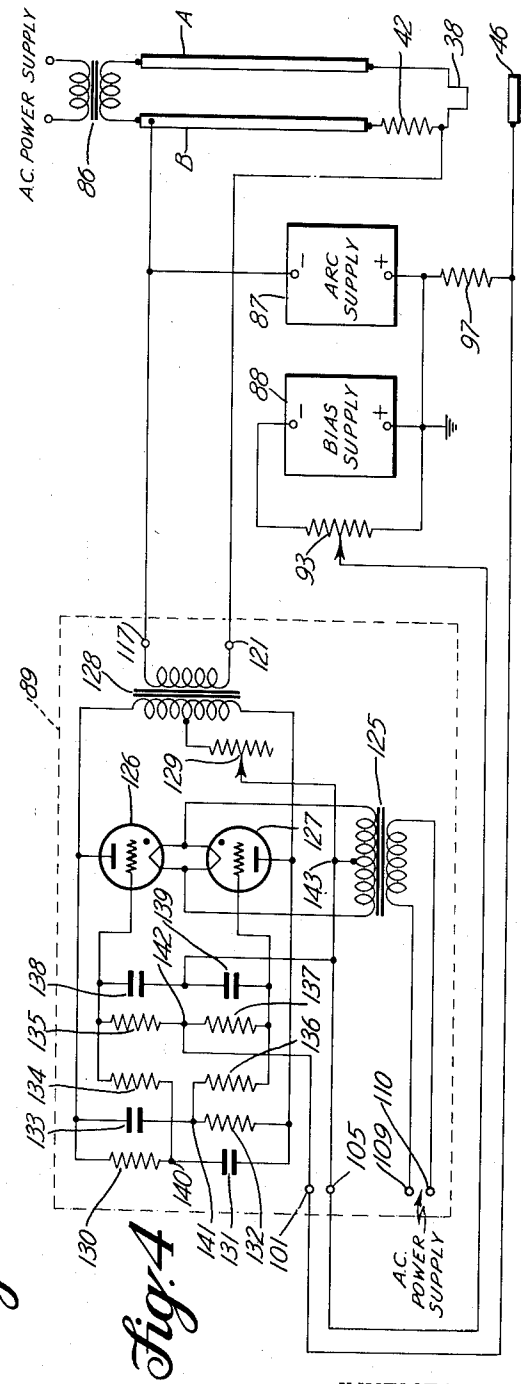


Fig. 4

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REGULATOR FOR CALUTRON ION SOURCE

Filed April 25, 1946 3 Sheets-Sheet 3

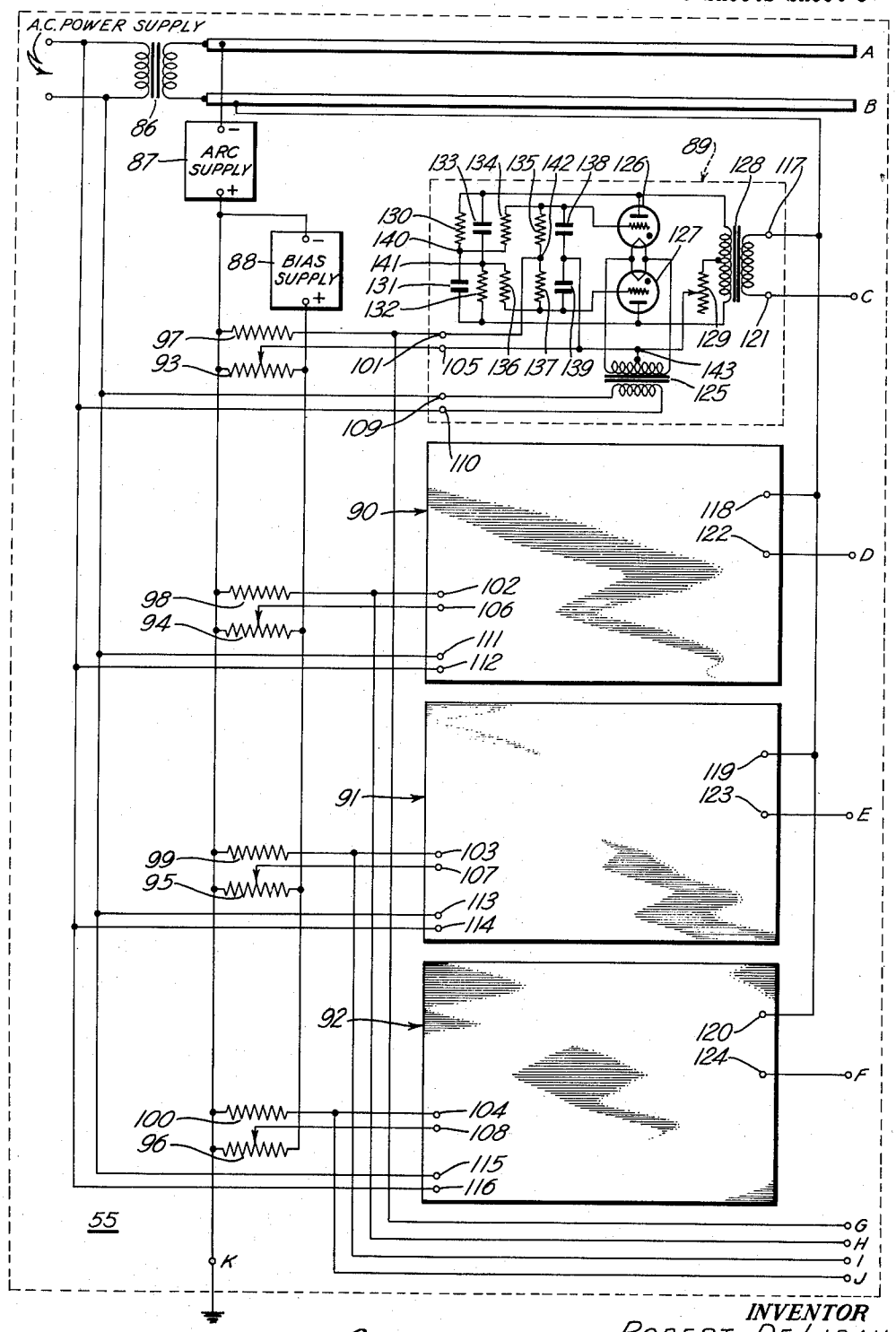


Fig. 3

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United States Patent Office

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REGULATOR FOR CALUTRON ION SOURCE

Robert De Liban, Berkeley, Calif., assignor to the United States of America as represented by the United States Atomic Energy Commission

Application April 25, 1946, Serial No. 664,735

10 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, now Patent No. 2,709,222, and Serial No. 536,401, filed May 19, 1944, now Patent No. 2,714,664.

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 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.

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 an auxiliary schematic wiring diagram for explanatory purposes, showing in a single drawing the connection of one of the four identical ion generator circuits illustrated in Figs. 1 and 3.

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. 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 blocks 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 and 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 are electrically connected to terminals J, I, H and G, respectively, of the arc supply and regulator apparatus 55. The terminal K of the arc supply and regulator apparatus 55 is connected to ground and also to the positive terminal of a suitable source of decelerating electrode supply, as explained more fully hereinafter. The collimating electrodes 47, 48, 49 and 50 are electrically connected to the associated ion source units 21 and 22, both of which are connected to ground. Likewise, the tank 13 is grounded. Also, the filament bus A is adapted to be operatively connected to the negative terminal of a suitable source of arc voltage supply 87, the positive terminal of which is operatively associated with the anodes 43, 44 45 and 46 via terminals J, I, H and G respectively, 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 end wall 18 also supports an ion decelerating structure 81 disposed adjacent the ion accelerating structure 57 but spaced apart therefrom. Both the ion accelerating structure and the ion decelerating structure have openings or slots formed therein in alignment with the slots 31, 32, 33 and 34 in the arc blocks, whereby unobstructed paths are formed for the ion beams emerging from slots 31, 32, 33 and 34, as described more fully hereinafter. The decelerating electrode supply 56 is adapted to be connected between the ion sources 21 and 22 and the decelerating structure 81, the positive and negative terminals of the supply mentioned being respectively connected to the ion sources 21 and 22 and to the ion decelerating structure 81. Further, the positive terminal of the decelerating supply 56 is grounded. The accelerating electrode supply 79 is adapted to be connected between the ion decelerating structure 81 and the ion accelerating structure 57, the positive terminal being connected to the ion decelerating structure and the negative terminal being connected to the ion accelerating structure. Thus the ion accelerating structure 57 is maintained at a high negative potential with respect to the grounded ion sources 21 and 22, this potential being equal to the sum of the accelerating electrode supply voltage and the decelerating electrode supply voltage; whereas the decelerating structure is maintained at a lower negative potential with respect to the grounded ion sources 21 and 22, this lower potential being equal to the decelerating electrode supply voltage.

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. The ion collector assembly 58 is electrically connected to the ion decelerating structure 81 and to the ungrounded negative terminal of the decelerating electrode supply 56.

Finally, a tank liner 80, formed of stainless steel or the like, is supported within tank 13, between the ion source units and the ion collector assembly 58. The liner is crescent shaped in plan with a tubular cross section, the ends being disposed adjacent the ion decelerating structure 81 and the ion collector assembly 58 respectively. Further, the liner 80 is connected electrically to the ion decelerating structure 81 and the ion collector assembly 58. Thus it will be understood that the ion source units 21 and 22 and the tank 13 are connected to the grounded positive terminal of the decelerating electrode supply 56; while the liner 80, the ion collector assembly 58 and the ion decelerating structure 81 are connected to the negative terminal of the decelerating electrode supply 56. This requires that the ion accelerating structure 57, the ion decelerating structure 81, the tank liner 80 and the ion collector assembly 58 be electrically insulated from the component parts of the tank 13. Thus the tank liner 80, disposed between the ion decelerating structure 81 and the ion collector assembly 58, constitutes an electrostatic shield for the high velocity ions traversing curved paths between the ion source units 21 and 22 and 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 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 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 87 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 accelertaed through the voltage impressed therebetween.

The positive ions then come under the influence of the ion decelerating structure 81 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 25, 26, 27 and 28 through the slots 31, 32, 33 and 34 formed in the walls thereof, across the space between the ion accelerating structure 57 and the adjacent walls of the arc blocks 25, 26, 27 and 28, through the slits 75, 76, 77 and 78, respectively, formed in the ion accelerating structure 57, across the space between the ion decelerating structure 81 and the ion accelerating structure 57 and thence through the slits 82, 83, 84 and 85 of the ion decelerating structure 81.

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, through the four aligned slits 75, 76, 77 and 78, respectively, and through the four aligned slits 82, 83, 84 and 85, respectively.

As previously noted, the ion collector assembly 58, as well as the tank liner 80, is electrically connected to the ion decelerating structure 81, whereby there is an electric-field-free path for the high velocity positive ions disposed between the ion decelerating structure 81 and the ion collector assembly 58 within the tank liner 80. 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 82, 83, 84 and 85, 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 receptacle 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 enrich 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.

The general arrangement and operation of the calutron 10 having been described, the circuits associated with the multiple ion source, to which this invention pertains, will now be considered. Referring to Fig. 3, which illustrates in detail the filament supply, arc supply and regulator unit 55 incorporated in Fig. 1, it is observed that four identical ion source regulating circuits are used, although certain components are common to each of the four channels. A common filament transformer 86, powered from a suitable source of alternating current, energizes through busses A and B the filament circuits comprising the filamentary cathodes 35, 36, 37 and 38 in series respectively with the filament resistors 39, 40, 41, and 42, shown in Fig. 1. A common arc supply 87 is connected with its negative terminal to bus A and with its positive terminal to ground, through terminal K, and to one end of each of the arc series resistors 97, 98, 99 and 100. The other ends of these resistors are connected through terminals G, H, I and J respectively to the arc anodes 43, 44, 45 and 46 in Fig. 1, and also to terminals 101, 102, 103 and 104 respectively of the variable impedance devices 89, 90, 91 and 92 in Fig. 3. Thus complete arc current circuits are formed, the arc electron current flowing from the negative terminal of the arc supply 87 through bus A to the filaments 35, 36, 37 and 38 and thence by electron emission through the collimating electrodes 25, 26, 27 and 28, respectively to the arc anodes 43, 44, 45 and 46, respectively, then through the arc series resistors 100, 99, 98 and 97 via terminals J, I, H and G to the positive terminal of arc supply 87. It is noted that a portion of the electron emission from the filaments may strike the corresponding collimating electrodes and return to the positive terminal of the arc supply

87 via ground and terminal K, but this is a relatively small portion because of the confining effect of the magnetic field upon the electron streams from the filaments. The arc current control potentiometers 93, 94, 95 and 96 are connected across a common bias supply 88, the negative terminal of this bias supply being also connected to the positive terminal of arc supply 87, which is grounded through terminal K. The variable contactors of potentiometers 93, 94, 95 and 96 are connected to terminals 105, 106, 107 and 108 respectively of the variable impedance devices 89, 90, 91 and 92. Thus a voltage proportional to the individual arc current is impressed between ground and the input terminals 101, 102, 103 and 104 of the respective variable impedance devices and, in addition, a variable standard voltage obtained from the arc current control potentiometers is impressed between ground and the input terminals 105, 106, 107 and 108 of the corresponding variable impedance devices. In other words, the difference voltages between the potentials developed in these series arc current resistors and the respective bias potentials selected by the arc current control potentiometers are impressed upon the input terminals of the corresponding variable impedance devices, these difference voltages being proportional to the individual arc currents. The output terminals 117, 118, 119 and 120 respectively of the variable impedance devices 89, 90, 91 and 92 are connected to the filament bus B. The other output terminals 121, 122, 123 and 124 are connected through terminals C, D, E and F respectively to the junctions of the corresponding filamentary cathodes and their filament series resistors shown in Fig. 1. Thus the variable impedance devices 89, 90, 91 and 92 provide in effect variable shunt impedances across the filament series resistors 39, 40, 41 and 42, respectively, the magnitude of this shunt impedance being controlled by the corresponding arc current. It is observed that filament busses A and B carry the main portion of the ion generator filament current, and that only enough current for regulating purposes flows through the output circuits of the variable impedance devices 89, 90, 91 and 92.

Considering now in more detail the circuit of the above-mentioned variable impedance devices, reference is made to Fig. 4 in which the complete circuit of a single regulating channel is shown. The circuit connections are identical with those shown in Figs. 1 and 3 except that the various components comprising one regulating channel are shown in a single diagram so that the cooperation between the various elements may be more readily apparent. Thus, all the elements and connections external to the variable impedance device 89 are connected in the manner heretofore described in connection with Figs. 1 and 3. Within the variable impedance device 89 transformer 125, powered from a suitable source of alternating current connected to terminals 109 and 110, supplies filament power for thyratron tubes 126 and 127. The anode voltages for these tubes are obtained from the secondary or transformer 128 the primary of which is connected in shunt with the filament series resistor 42 via terminals 117 and 121. Thus this transformer 128 is energized by a portion of the filament current flowing through its primary winding. The various resistive and capacitative elements appearing in the grid circuits of thyratron tubes 126 and 127 comprise a phasing circuit that combines properly pre-phased A. C. signals with the D. C. signal appearing across terminals 101 and 105, whereby the firing points of thyratron tubes 126 and 127 may be controlled by the D. C. signal. Tubes 126 and 127 in turn determine the current flow in the primary of transformer 128 and hence the effective impedance appearing across terminals 117 and 121. It is observed, however, that this impedance is not actually a continuously variable quantity. Instead it alternates between two fixed values, the higher of which is determined by the open circuit impedance of transformer 128 when tubes 126 and 127 are not fired, and the lower of which depends for the most part upon the potential drop across thyratron tubes 126 and 127 when they are conducting, upon the turns ratio of transformer 128 and upon the value of resistor 129. Thus the amount of filament current flowing through the primary of transformer 128 will also alternate between two values, the fraction of each half cycle that it flows at each of these values being determined by the firing points of the tubes 126 and 127. However, because of the thermal delay in filamentary cathode 38 these abrupt cyclic current changes do not appear in the emission of the filament so that the variable impedance device 89 can actually be considered as presenting a continuously variable impedance across resistor 42, as far as the effect on the filament emission is concerned.

Considering now the operation of the above-mentioned phasing circuit associated with the grids of thyratron tubes 126 and 127, it is seen that the network comprising resistor 130 and capacitor 131 and the network comprising resistor 132 and capacitor 133 are connected across the extremities of the secondary winding of transformer 128. Capacitors 131 and 133 are equal in value, as are resistors 130 and 132. Also, the reactance of these capacitors at the supply line frequency is equal to the value of these resistors. Consequently the voltage appearing between the junction 140 of resistor 130 and capacitor 131 and the secondary center-tap 143 of transformer 125 will be approximately equal in magnitude to the potential between the anode of tube 126 and the center-tap 143, and will lag this voltage in phase by approximately 90°. Similarly the potential appearing between the junction point 141 of resistor 132 and capacitor 133 and center-tap 143 will be approximately equal in magnitude to, but will lag approximately 90° behind, the anode voltage of thyratron tube 127. Resistors 134 and 135 and resistors 136 and 137 comprise two identical voltage dividers connected in series between junction points 140 and 141. These dividers are of relatively high impedance so that their small shunting effect does not appreciably disturb the above-mentioned voltage relationships. Further, resistors 134 and 136 are high in value compared to resistors 135 and 137 so that the potentials appearing across these latter two resistors are smaller in magnitude than, but of the same phase as, those appearing respectively between junction points 140 and 143 and between junction point 141 and 143. Thus there are developed between the junction point 142 and the grids of tubes 126 and 127, which are connected to resistors 135 and 137, A. C. grid voltages of the correct phase and magnitude for the control of tubes 126 and 127.

But, because of symmetry, point 142 is at the same A. C. potential as the secondary center-tap of transformer 128, and this in turn is at the same potential as point 143, since there is no potential drop across resistor 129 until the tubes 126 and 127 are fired during each A. C. cycle. Thus the above-mentioned A. C. grid voltages appearing across resistors 135 and 137 are in effect impressed between the control grids and the cathodes of tubes 126 and 127. Capacitors 138 and 139 insure proper firing of tubes 126 and 127 by by-passing any high frequency transients that might reach the tube's grids by way of wiring pick-up or coupling through the grid-plate tube capacities.

The D. C. signal appearing across terminals 101 and 105 is also impressed between the cathodes and grids of tubes 126 and 127, via junction points 142 and 143, both of which are neutral with respect to A. C. Some of this D. C. signal is lost across resistors 135 and 137, but this is a small fraction since these resistors are low in value compared to the remaining resistance of the D. C. path between points 142 and 143. It is apparent then that the total potential impressed between the cathodes and grids of tubes 126 and 127 consists of a large fraction of the D. C. signal across terminals 101 and 105 plus the A. C. voltages appearing across resistors 135 and 137,

these A. C. voltages lagging the respective anode voltages by approximately 90°. Thus the phasing circuit, by properly combining these voltages, effects control of the firing points of thyratron tubes **126** and **127** in response to a signal derived from the arc current.

In the operation of the complete regulating loop if the arc current tends to increase a more negative potential is applied between the grids of tubes **126** and **127** and their filaments causing the tubes to fire later in the cycle. Thus the portion of the filament current flowing through the primary of transformer **128** will be at a low value for a greater portion of each alternating current cycle, thereby reducing the average alternating current supplied filament 38. The resulting drop in emission tends to restore the arc current to its original value. In this manner the arc current is stabilized.

In a similar manner the remaining regulating circuits shown in Fig. 3 function to regulate the arc currents flowing to anodes **43**, **44** and **45** in Fig. 1. Thus each arc current may be controlled independently although common filament, arc and bias supplies are used.

It is apparent that the regulating system is not limited to the number of channels shown. In fact, if the number of independent arcs is increased the advantages of the regulating circuit become greater, since the additional equipment required need only handle the low current necessary for regulation of the filaments.

It is also observed that this regulating circuit is not limited to the particular calutron arrangement shown. For instance, it would operate equally as well if the ion generators were operated at a high potential from ground and the ion receivers were at ground potential.

While there has been described what is at present considered to be the preferred embodiment 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 feeders for supplying heating current to said cathode through said resistor, a variable impedance apparatus connected across said resistor, said variable impedance apparatus including gas discharge device means, and means for controlling said gas discharge device means in accordance with the arc current between said anode and said cathode, whereby the current to said cathode is controlled to maintain said arc current 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 feeders for supplying heating current to said cathode through said resistor, means for producing a magnetic field aligned between said cathode and said anode, a variable impedance apparatus connected across said resistor, said variable impedance apparatus including gas discharge device means, and means for controlling said gas discharge device means in accordance with the arc current between said anode and said cathode, whereby the current to said cathode is controlled to maintain said arc current 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 feeders for supplying heating current to said cathode through said resistor, a variable impedance apparatus connected across said resistor, said variable impedance apparatus including gas discharge device means, and means for controlling said gas discharge device means in accordance with the arc current between said anode and said cathode, whereby the current to said cathode is controlled to maintain said arc current 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, means for producing a magnetic field aligned between said cathode and said anode, a resistor, a pair of feeders for supplying heating current to said cathode through said resistor, a variable impedance apparatus connected across said resistor, said variable impedance apparatus including gas discharge device means, and means for controlling said gas discharge device means in accordance with the arc current between said anode and said cathode, whereby the current to said cathode is controlled to maintain said arc current substantially constant.

5. 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 feeders for supplying heating current to said cathode through said resistor, a source of arc current supply connected to said anode and said cathode, a variable impedance apparatus having a winding connected across said resistor, said variable impedance apparatus having a second winding and a gaseous discharge device for controlling the current through said second winding, and means connected between said source of arc current supply and said gaseous discharge device whereby the impedance of said first-mentioned winding is controlled to control the current to said cathode over a predetermined range.

6. 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 feeders for supplying heating current to said cathode through said resistor, a source of arc current supply connected to said anode and said cathode, a variable impedance apparatus having a winding connected across said resistor, said variable impedance apparatus having a second winding and a gaseous discharge device for controlling the current through said second winding, means connected betwen said source of arc current supply and said gaseous discharge device whereby the impedance of said first-mentioned winding is controlled to control the current to said cathode over a predetermined range, and means for producing a magnetic field through said ion source, said magnetic field being of a magnitude and direction to substantially confine 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 resistor connected in series with said cathode, 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 transformer having a winding connected across said resistor to control the heating current to said cathode over a predetermined range, a pair of thyratrons, said transformer having a second winding with the terminals thereof connected to the anodes of said thyratrons, a phasing circuit associated with the grids of said thyratrons, and means for applying a potential varying in accordance with the arc current to said phasing circuit for controlling the impedance of said first winding substantially in accordance with said arc current.

8. A regulator for a multiple ion source calutron comprising in combination a plurality of iron sources each having an anode and a cathode, a plurality of resistors,

one of said resistors being connected in series with each of said cathodes, a pair of relatively heavy primary feeders for supplying heating current to all of said cathodes, a plurality of relatively small conductors, one of said relatively small conductors being connected to each of the common terminals between said series connected resistors and said cathodes for individually regulating the heating current supplied to said cathodes, a plurality of variable impedance apparatus, one of said apparatus being connected to each of said relatively light conductors for individually controlling the regulating current to said cathodes, a source of arc current supply connected between said anodes and said cathodes, and means for developing potential drops individually varying in magnitude in accordance with the arc currents for controlling each of said variable impedance apparatus to regulate said ion sources individually.

9. 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 transformer having a winding connected to control the heating current to said cathode over a predetermined range, a pair of thyratrons, said transformer having a second winding having the terminals thereof connected to the anodes of said thyratrons, a phasing circuit energized from the anodes of said thyratrons for controlling the grids of said thyratrons, and means for applying a potential varying in accordance with the arc current to said phasing circuit for controlling the impedance of said first winding substantially in accordance with said arc 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 resistor connected in series with said cathode, a source of arc current supply connected between said cathode and said anode, a transformer having a winding connected across said resistor to control the heating current to said cathode over a predetermined range, a pair of thyratrons, said transformer having a second winding having the terminals thereof connected to the anodes of said thyratrons, a phasing circuit supplied from the anodes of said thyratrons for controlling the grids of said thyratrons, and means for applying a potential varying in accordance with the arc current to said phasing circuit for controlling the impedance of said first winding substantially in accordance with said arc current.

No references cited.