June 28, 1955 J. SAYERS 2,712,072

CALUTRON ION SOURCE

Filed June 30, 1948 2 Sheets-Sheet 1

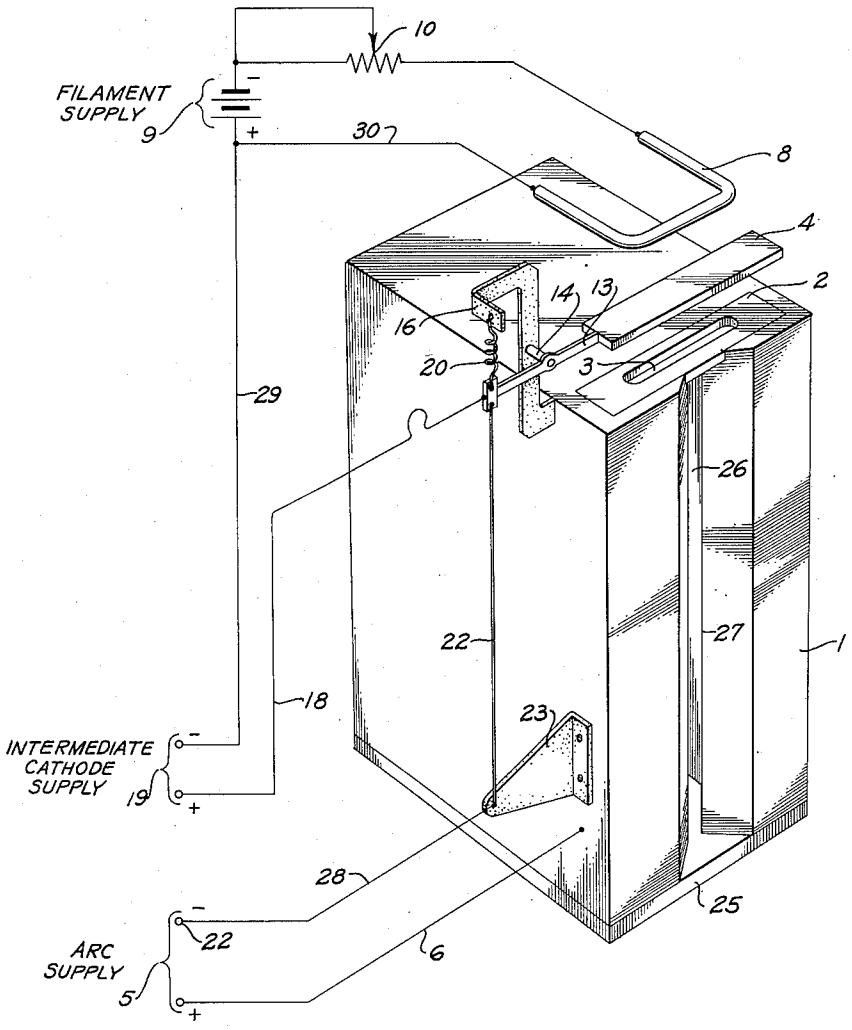


Fig. 1

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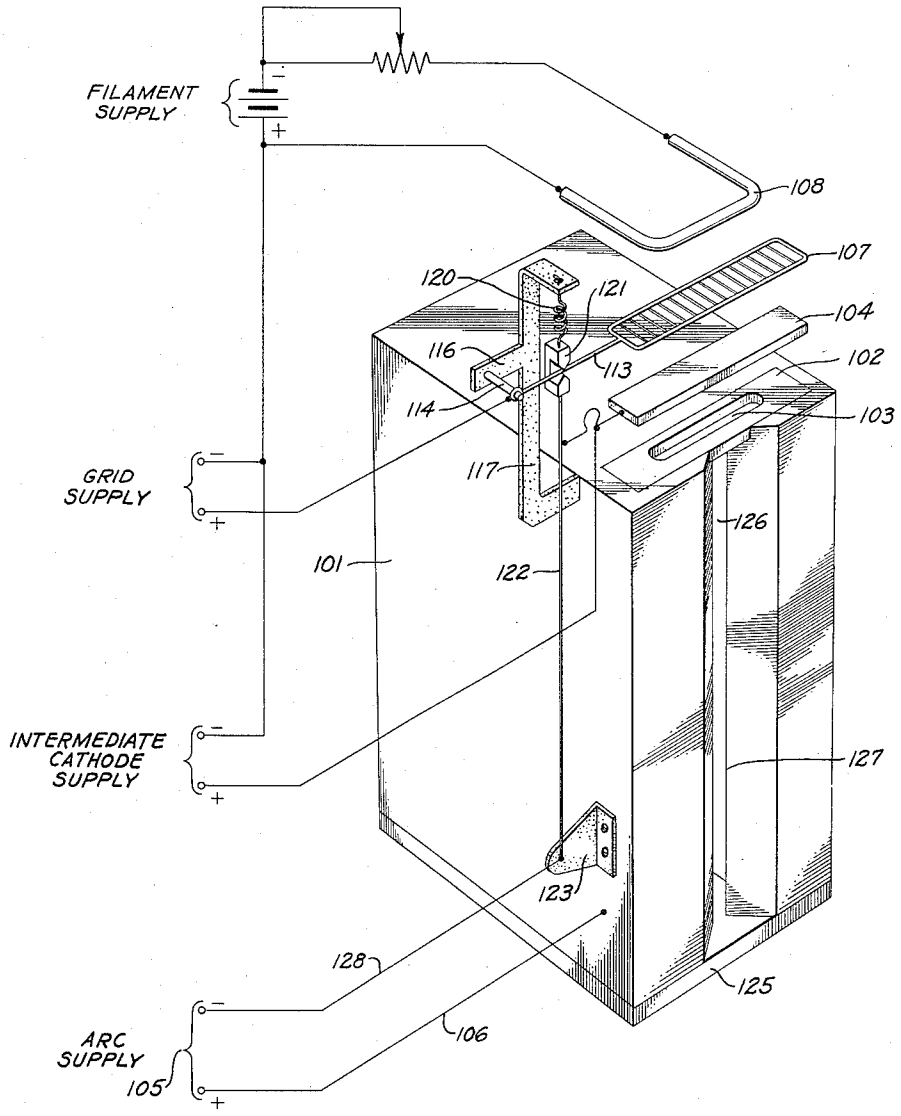


Fig. 2

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CALUTRON ION SOURCE

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9 Claims. (Cl. 250—41.9)

This invention relates to calutrons and more particularly to an electrode arrangement for automatically regulating the arc current of the ion generator for a calutron. This application is a continuation-in-part of copending application, Serial No. 692,459, filed August 23, 1946, now abandoned.

Calutrons are described in general in "Atomic Energy for Military Purposes," by H. D. Smyth, and in great detail in the co-pending application of Ernest O. Lawrence, Serial No. 557,784, filed October 9, 1944.

Calutrons are principally employed in separating the isotopes of the elements. They are adaptable to the separation of macroscopic amounts of any mixture of isotopes which may be ionized.

In general, an ion source projects ions of a polyisotopic material into a magnetic field. Thereafter, the ions travel in curved paths through the magnetic field, the ions of greater mass describing paths with flatter curves than the ions of lighter mass. Collectors are disposed at suitable points along each path, preferably at the 180° point in the curved travel in order to discharge and collect the ions of the different paths. In this manner the atoms of different mass that were originally in the polyisotopic mixture are distributed in different regions and thereby substantially separated from one another.

The degree of separation of the isotopes which is thus achieved will depend largely upon the stability of the forces acting to produce the aforementioned paths and the accuracy with which the beam is directed upon the collector elements. These forces are the result of the magnetic field and the accelerating potential employed. Various means are employed to regulate the magnetic field and accelerating potential and to keep them relatively constant. It is also highly desirable that a relatively intense, stable beam of positive ions be projected from the ion generator by the accelerating structure through the liner to the collector elements, which operating condition requires that the ion generator presents to the accelerating structure a high density plasma surface which is extremely stable in shape, position, and ion density. In order to obtain such a plasma surface, the rate of ion production by the arc discharge in the ion generator must be substantially constant. This has been accomplished by controlling the heating energy applied to the arc cathode plate inversely as the arc current.

It is therefore an object of this invention to provide a regulator for stabilizing the operation of an ion generator.

Another object of this invention is to provide a regulator for stabilizing the operation of an ion generator of the arc discharge type.

Still another object of this invention is to provide a regulator for an ion generator of the hot cathode arc discharge type which has a highly stable rate of ion production.

A further object of this invention is to provide a cathode heated by electron bombardment that is automatically regulated so as to be electron emissive to a predetermined value.

The invention, both as to its organization and method of operation together with other objects and advantages thereof, will best be understood by reference to the following specification taken in conjunction with the accompanying drawings, in which:

Figure 1 is an isometric view of an ion generator comprising an arc block, a movable arc cathode and a filamentary cathode;

Fig. 2 is an isometric view of another embodiment of the invention in which the ion generator comprises an arc block, a fixed arc cathode plate, a movable grid and a filamentary cathode.

Referring particularly to Fig. 1, an ion generator of the arc discharge type is shown. An arc block **1** contains an arc discharge chamber **26** visible through an arc slit **27**. The arc block **1** also contains a charge receptacle (not shown) and a communicating passage between the charge bottle and the arc discharge chamber **26**. Mounted on the arc block **1** and centered over the arc chamber **26** is a collimating electrode **2** containing a collimating slot **3**. Mounted adjacent to the collimating electrode **2** and in line with the collimating electrode **2** and the arc chamber **26** is a movable arc cathode **4**. This movable cathode **4** is supported by a lever arm **13** which is pivotally mounted by a pin **14** on a support bracket **16**. A wire **22** has one of its ends attached to a nonconducting support **23**, and its other end attached to the outboard end of the lever arm **13**. One end of a spring **20** is attached to the same end of the lever arm **13** as is one end of the wire **22**. The other end of the spring **20** is attached to the nonconducting support bracket **16**. Thus the spring **20** tends to keep the wire **22** taut at all times. A filamentary cathode **8** is mounted adjacent to the arc cathode plate **4**.

Suitable supplies of voltage and current are connected to the various units. The arc supply **5** has its positive terminal connected through a wire **6** to the arc block **1** and its negative terminal connected through wire **28** to the end of the control wire **22** which is attached to the nonconducting support **23**. Thus the total arc current of the arc discharge which takes place between the arc cathode plate **4** and a bottom plate **25** of the arc block **1**, flows through the control wire **22**. An intermediate cathode supply **19** has its positive terminal connected to the arc cathode **4** through a wire **18** and the lever arm **13**, and its negative terminal connected through a wire **29** to one terminal of a filament supply **9**. This same terminal of the filament supply **9** is connected through a wire **30** to the filamentary cathode **8**. The other terminal of the filament supply **9** is connected through a variable resistor **10** to the other end of filamentary cathode **8**. By means of the variable resistor **10** the amount of current flowing in the filamentary cathode **8** can be controlled and thus its temperature can be controlled. The operation of the ion generator shown in Fig. 1 is conducted in a homogeneous magnetic field in which the lines of flux are parallel to the arc slit **27**. Conventional heaters (not shown) surround the charge receptacle for heating the arc block. After the arc block and the charge receptacle have been brought up to the correct operating temperature, the material contained in the charge bottle which has been vaporized by this heat is allowed to flow out into the arc chamber. The circuit to the filamentary cathode **8** is then closed, and the current flowing through the filamentary cathode **8** causes heating of the same. The amount of current flowing through the filamentary cathode **8**, and, therefore, its temperature, may be controlled by the variable resistor **10**. The temperature of the filamentary cathode **8** is adjusted by means of variable re-

sistor 10 so that thermionic emission takes place from said filamentary cathode.

The circuit to the intermediate cathode supply 19 is then closed. The electrons which have been emitted by filamentary cathode 8 are immediately attracted to the arc cathode plate 4. The arc cathode plate 4 is heated to a thermionically emissive temperature by electron bombardment from the filamentary cathode 8, and the electrons emitted from the arc cathode plate 4 are accelerated downward into the arc block 1 as soon as the connection to the arc supply 5 is completed. An arc discharge thus takes place between the arc cathode plate 4 and the arc chamber bottom plate 25.

The purpose of the collimating slot 3 in collimating plate 2 is to give the arc discharge within the arc chamber 26 a desired configuration, which is accomplished by forming a slot of requisite cross section in the collimating plate 2 and allowing the arc discharge to pass therethrough.

The arc discharge as it passes through the arc chamber 26 ionizes the vapor within said arc chamber, producing ions of the material contained within the charge receptacle.

The automatic control features of this ion generator operate in the following manner: Referring again to Fig. 1, it will be seen that the arc current (electron flow) flows from the negative terminal of the arc supply 5 through the connecting wire 28, then through the control wire 22 to the lever arm 13 and thus to the arc cathode 4. The arc current then flows in the form of an arc discharge to the bottom plate 25 of the arc chamber 1 and thence through the return wire 6 to the arc supply 5. Thus it is apparent that the total arc current flows through the control wire 22. This control wire 22 has been chosen of such diameter that the correct operating arc current will heat the wire 22 to a temperature approaching a dull red heat or a temperature much higher than that of the surrounding apparatus. Under these conditions the temperature of the wire 22, in accordance with the coefficient of expansion thereof, controls its length and is dependent only upon the arc current.

The arc current is controlled by the number of thermionic electrons emitted from the arc cathode plate 4, which quantity is determined by the temperature of the arc cathode plate 4, and the temperature is in turn determined by the amount of electron bombardment received from the filamentary cathode 8.

The operating constants are preferably so selected that the current flowing between the filamentary cathode 8 and the arc cathode plate 4 is space-charge limited, and thus the current varies inversely as the distance between the cathodes 8 and 4.

Assuming that the ion generator has been placed in operation as described above, that the operating arc current has been set at the desired predetermined value, and that the control wire 22 has been heated to an elevated temperature by the passage of arc current therethrough, then, when the arc current increases, the control wire 22, due to an increase in temperature, elongates and allows the spring 20 to pivot the lever arm 13 about the pin 14. This moves the arc cathode plate 4 farther away from the filamentary cathode 8 and decreases the bombardment intensity of the arc cathode 4 and therefore its temperature decreases accordingly. The decrease in temperature causes the arc cathode 4 to emit fewer electrons, thereby reducing the arc current. In this manner the arc current is automatically decreased if, during operation, it exceeds the original predetermined value. Conversely, if the arc current decreases, the control wire 22 cools and in cooling its length becomes less. This decrease in length, acting against spring 20, pivots the lever arm 13 about the pin 14. This action causes the arc cathode plate 4 to move closer to the filamentary cathode 8, which increases the amount of bombardment that the arc cathode plate receives, and in turn raises the temperature of the arc cathode plate 4. This increase in temperature of the arc cathode plate 4 causes emission of a greater number of electrons which in turn increases the arc current. In this manner a mechanism is provided whereby the arc current may be maintained substantially constant.

Referring to Fig. 2, a second embodiment of the invention is shown. In this figure an ion generator is shown which is similar in some respects to that of Fig. 1, but by the addition of a grid as hereinafter described, more precise control of the arc current may be effected.

This second embodiment of the invention as shown in Fig. 2 comprises an arc block 101 which contains an arc discharge chamber 126 visible through an arc slit 127. The arc block 101 also contains a charge receptacle (not shown) and a communicating passageway between the charge bottle and the arc discharge chamber 126. Mounted on the arc block 101 and centered over the arc chamber 126 is a collimating electrode 102 containing a collimating slot 103. Mounted adjacent to the collimating electrode 102 and in line with the collimating electrode 102 and the arc chamber 126 is a fixed arc cathode 104. A movable grid 107 is mounted adjacent to the arc cathode 104. The movable grid 107 is supported by a lever arm 113 which is pivotally mounted by a pin 114 on one arm 116 of a support bracket 117. A wire 122 has one of its ends attached to a nonconducting support 123 and its other end attached to a knife-edge block 121. Also attached to the knife-edge block 121 is one end of a spring 120; the other end of the spring 120 is attached to the support bracket 117. The spring 120 is arranged so that it will keep the wire 122 taut at all times.

The knife-edge block 121 operates on the lever arm 113 and rotates this lever arm 113 about the pivot pin 114, thereby moving the grid 107 with respect to the fixed arc cathode plate 104. Situated in line with the collimating slot 103, the fixed arc cathode plate 104, and the grid 107, and also adjacent to the grid 107, is the filamentary cathode 108.

Referring again to Figs. 1 and 2, which show the first and second embodiments of this invention respectively, it is seen that the first embodiment uses a filamentary cathode 8 and a movable arc cathode plate 4; the spacing between the filamentary cathode 8 and the movable arc cathode plate 4 is controlled by the thermally responsive wire 22.

In the second embodiment of this invention, as shown in Fig. 2, it is seen that the arc cathode plate 104 is fixed in position relative to the filamentary cathode 108; and interposed between the filamentary cathode 108 and the fixed arc cathode plate 104 is a movable grid 107, whose position relative to the filamentary cathode 108 and the arc cathode plate 104 is determined by a thermally responsive wire 122.

Thus it is seen that in the first embodiment the position of the arc cathode plate 4 is varied with respect to the filamentary cathode 8, and in the second embodiment the position of a movable grid 107 is varied with respect to a filamentary cathode 108 and a fixed arc cathode plate 104.

Consideration will now be given to the theory of operation of the form of the invention shown in Fig. 2. It is well known in the art that a triode comprising a filament, a grid, and an anode, having suitable supplies of voltage and current connected thereto, will allow a definite current flow between the filament and anode; this current being determined by the geometry of the triode. If the voltages applied to the filament, the grid, and the anode of the triode are held constant, then the electron current which is flowing between the filament and the anode can be varied by allowing the grid to move back and forth between the filament and the anode. If the grid is allowed to move away from the anode and toward the filament, it has a greater influence on the electron stream than before and there will be fewer electrons reaching the anode and therefore less current will flow be-

tween the filament and anode. Conversely, if the grid moves toward the anode and away from the filament, the grid will have less influence on the electron stream than before and more electrons will reach the anode and therefore more current will flow between the filament and anode.

Returning again to Fig. 2, there is disclosed an ion generator similar in many respects to that disclosed in Fig. 1. A movable grid **107** is interposed between filamentary cathode **108** and fixed arc cathode plate **104**. This movable grid **107** controls the electron bombardment of arc cathode **104** according to the relative position of the grid with respect to the filamentary cathode **108** and the arc cathode plate **104**.

The actual regulating action of the ion generator disclosed in Fig. 2 will now be described. This ion generator is placed in operation in much the same way that the generator shown in Fig. 1 is placed in operation. The connections to the various supplies are completed and the arc block **101** brought up to the correct temperature; then the arc discharge is started between the arc cathode plate **104** and the bottom plate **125** of the arc block **101**. The arc current is adjusted until the conditions are optimum for ionization of the vapor released from the charge receptacle.

Referring to Fig. 2, we see that the arc current (electron flow) flows from the negative terminal of the arc supply **105**, through the wire **128** to one end of the control wire **122**; through the control wire **122** and finally to the arc cathode plate **104** through a short jumper from the control wire **122**. The arc current then flows as an arc discharge from the arc cathode plate **104** to the bottom plate **125** of arc block **101** and thence returns through the wire **106** to the positive terminal of the arc supply **105**. Thus it is apparent from this description that the total arc current flows through the control wire **122**.

When the arc current increases, the control wire **122** becomes hotter; and hence the control wire **122** increases in length thereby allowing the spring **120**, acting through the knife-edge block **121**, to rotate the lever arm **113** about pivot **114**. This allows the grid **107** to move closer to the filamentary cathode **108** and to move farther away from the arc cathode plate **104**. This action causes the arc cathode plate **104** to exert less attractive influence on the electrons which are emitted from the filamentary cathode **108**. The decrease in the electron bombardment of the arc cathode plate **104** allows its temperature to decrease accordingly and the arc cathode **104** to emit fewer electrons, thereby reducing the arc current. In this manner the arc current is automatically decreased if, during operation, it exceeds the original predetermined value.

Conversely, if the arc current decreases, the control wire cools and in cooling its length becomes less. This decrease in length, acting in opposition to spring **120**, operates on lever arm **113** through knife-edge block **121**, and rotates lever arm **113** on pivot **114**. As lever arm **113** rotates about pivot **114**, it causes grid **107** to move away from filamentary cathode **108** and toward arc cathode plate **104**. This action allows the arc cathode plate to exert a greater attractive influence on the electrons which are emitted from the filamentary cathode **108**, which in turn increases the amount of bombardment that the arc cathode plate **104** receives, and, therefore, its temperature increases accordingly. This increase in temperature of the arc cathode plate **104** causes emission of a greater number of electrons which in turn increases the arc current.

In this manner a mechanism is provided whereby the arc current may be maintained substantially constant.

Although I have described my invention with respect to a particular embodiment thereof, it is not limited to this embodiment nor otherwise except by the terms of the following claims.

What is claimed is:

1. An ion generator comprising an ionization chamber, a filamentary cathode in spaced relation to said ionization chamber, a grid pivotally disposed therebetween, an arc cathode located between said grid and said ionization chamber, electrical source means connected to said cathodes for establishing electron flow therebetween, a second electrical source means connected between said grid and said filamentary cathode for supplying grid bias voltage, and a third electrical source means for establishing electron flow between said arc cathode and said ionization chamber, said arc cathode being electrically connected to said third source by a thermally responsive conductor having insulated means connected to said grid for varying the position of said grid in response to changes in current flowing through said conductor.

2. In a calutron, an ion generator comprising an arc block having an arc chamber and an arc slit formed therein and a magnetic field parallel to said arc slit passing therethrough, said arc block containing conventional heaters and a charge receptacle of a material to be ionized, an arc anode plate covering one end of said arc chamber, a collimating plate having a predetermined aperture formed therein covering the other end of said arc chamber, an arc cathode disposed above said collimating plate and in line with said aperture, said arc cathode having at least two electrodes of variable spacing, one of said electrodes being pivotally mounted, a thermally expansible conductor connected to said movable electrode at one end and having its other end attached to an insulating support bracket, tension means for positioning said movable electrode for initially positioning said movable electrode in a predetermined position, a first source of voltage connected to said arc cathode electrodes for establishing electron flow therebetween, a second source of voltage connected to said thermally expansible conductor and to said arc anode plate for establishing an arc discharge in said arc chamber, said thermally expansible conductor varying in length with the current flowing therethrough, said variations in length serving to vary the spacing of the arc cathode electrodes thereby altering the quantity of electrons emitted by said arc cathode so as to maintain the current flowing in said arc discharge substantially constant.

3. In an arc discharge device, the combination comprising a plurality of electrodes having the paths therebetween in alignment, at least two of said electrodes serving as an arc cathode and one an arc anode, voltage supply means connected to said electrodes for impressing operating voltages thereon, one of said arc cathode electrodes having a lever arm extended therefrom which is pivotally mounted at a fulcrum disposed to one side of said paths, a thermally responsive conductor, variable in length upon heating by a current flowing therethrough, connected to said lever arm at one end and extending substantially parallel to said paths to a fixed point, and means for connecting said conductor between said arc anode and said voltage supply means whereby the position of said one of said arc cathode electrodes relative to the other of said electrodes is changed in response to the heating produced by said current.

4. An ion source comprising a plurality of electrodes having the paths therebetween in alignment, at least two of said electrodes serving as an arc cathode and one an arc anode, structure defining an ionization chamber disposed between said arc cathode and anode, one of said arc cathode electrodes having a lever arm extending therefrom which is pivotally mounted at a fulcrum supported on said structure to one side of said paths, a thermally responsive conductor, variable in length upon heating by a current flowing therethrough, connected to said lever arm at one end and extending substantially parallel to said paths to a fixed point on said structure, voltage

supply means connected to said electrodes for impressing operating voltages thereon, said conductor being included in said operating voltage connections so that current flow between said arc cathode and anode flows therethrough whereby the position of said one of said arc cathode electrodes relative to the other of said electrodes is changed in response to the heating produced by said current.

5. An ion source comprising an arc cathode of the bombardment heated type having a plurality of electrodes, an arc anode disposed in spaced-apart relation to said arc cathode, an arc block having an ionization chamber therein disposed between said arc cathode and anode, one of said arc cathode electrodes having a laterally extending lever arm pivoted at a fulcrum supported on said arc block to one side of the path between said arc cathode and anode, a thermally responsive conductor, variable in length upon heating by a current flowing therethrough, connected to said lever arm at one end and extending substantially parallel to said path to a fixed point on said arc block, a first source of voltage connected to said arc cathode electrodes for impressing operating voltages thereon and for rendering said arc cathode electron emissive, a second source of voltage connected between said arc cathode and anode for establishing an arc therebetween, said last named connections including said conductor so that the arc current is carried thereby whereby the position of said one of said arc cathode electrodes is changed in response to the heating produced in said conductor by said arc current.

6. An ion generator comprising an ionization chamber, an arc cathode having a plurality of electrodes for supplying a stream of electrons into said ionization chamber, one of said electrodes having an elongated portion extending to a fulcrum disposed to one side of the path between said electrodes and being movable about said fulcrum, a first electrical source connected to said arc cathode electrodes for establishing electron flow therebetween, a second electrical source connected by electrical conductors to said arc cathode and ionization chamber for establishing an arc discharge therebetween, one of said conductors, being thermally expansible and varying in length with variations of current flowing therethrough, connected to said elongated electrode portion and extending parallel to said path to a fixed point whereby variations in length of said conductor upon heating by said arc current varies the position of said movable electrode to maintain said arc current substantially constant.

7. An ion generator comprising structure forming an ionization chamber, a bombardment heated cathode in spaced relation thereto, a filamentary cathode disposed adjacent to and in alignment with said bombardment cathode, a first voltage source connected between said cathodes for rendering said bombardment cathode electron emissive, said bombardment cathode having a laterally extending lever arm pivoted at a fulcrum supported on said structure to one side of the path between said cathodes, a thermally responsive conductor, variable in length upon heating by a current flowing therethrough, connected to said lever arm at one end and extending substantially parallel to said path to a fixed point on said structure, and a second voltage source connected between said bombardment cathode and said structure for establishing an arc therebetween through said chamber, said last named connections including said conductor so that the arc current is carried thereby whereby the position of said bombardment cathode is changed in response to the heating produced in said conductor by said arc current.

8. In a calutron, an ion source comprising an arc block having an arc chamber and an arc slit formed therein, said arc block also having a magnetic field therethrough, a collimating plate having a predetermined aperture formed therein disposed at one end of said arc chamber, an arc cathode of the bombardment heated type having a plurality of electrodes disposed in spaced relation with said arc block and overlying said aperture, the paths between said electrodes being parallel to said magnetic field, one of said electrodes having a laterally extending lever arm pivoted at a fulcrum supported on said arc block to one side of said paths, a thermally responsive conductor, variable in length upon heating by a current flowing therethrough, connected to said lever arm at one end and extending substantially parallel to said magnetic field to a fixed point on said arc block, a first source of voltage connected to said electrodes for impressing operating voltages thereon and for rendering said arc cathode electron emissive, a second source of voltage connected between said arc cathode and arc block for establishing an arc through said chamber, said last named connections including said conductor so that the arc current is carried thereby whereby the position of said one of said electrodes is changed in response to the heating produced by said arc current.

9. An ion generator comprising an ionization chamber, a filamentary cathode in spaced relation to said ionization chamber, an arc cathode pivotally disposed between said filamentary cathode and said ionization chamber, electrical source means connected to said cathodes for establishing electron flow therebetween, a second electrical source means connected between said arc cathode and said ionization chamber for establishing electron flow therebetween, said arc cathode being electrically connected to said second source by a thermally responsive conductor for varying the position of said arc cathode in response to changes in current flowing through said conductor.

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