Oct. 2, 1951 K. G. HERNQVIST 2,570,124

POSITIVE ION BEAM GUN

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Fig_1

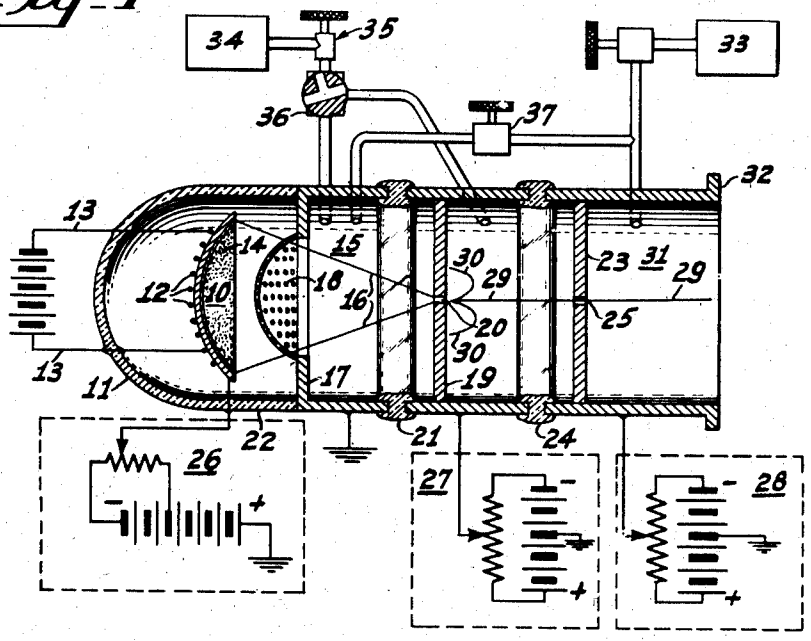


Fig_2

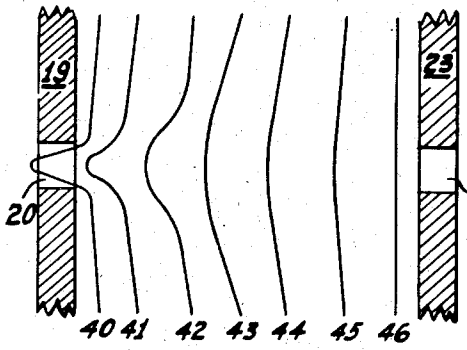
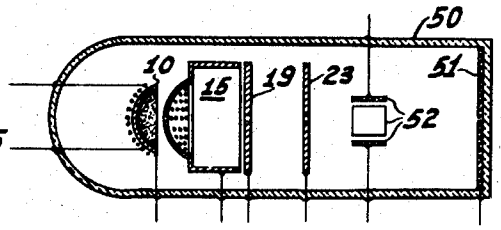


Fig_3



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POSITIVE ION BEAM GUN

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14 Claims. (Cl. 313—230)

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This invention relates to improvements in positive ion beam guns and particularly to improvements therein by which it is possible to produce ion beams of greatly increased current densities.

As is known, there are certain types of devices for which sources of positive ion beams are required, for example, mass spectrographs, cyclotrons and linear accelerators. While sources of this kind have been available in the past, their beams have often been of insufficient current densities and they have been difficult to operate.

One type of positive ion beam gun has been an apparatus comprising an ionization chamber having a gas atmosphere, means for ionizing the gas by glow discharge, a small beam-forming orifice in a wall of the chamber, a circuit for causing said wall to be somewhat more negative than other portions of the chamber to draw positive ions towards its inside surface, and a negatively polarized external electrode for drawing positive ions through said orifice into a utilization chamber such as into the evacuated envelope of a cyclotron. In such an apparatus the only ions drawn through the orifice are those which, in moving at random within said chamber and adjacent to said wall, happen to pass across or near to the orifice therein. Because of this, a beam of small density is usually produced and in order to obtain adequate current it is usually necessary to use a fairly high gas pressure and a fairly large orifice. However, these two conditions, particularly when they co-exist, make it difficult to maintain a hard vacuum in the utilization chamber.

For some time it has been desirable to devise an improved positive ion gun in which it would be possible to use an extremely low gas pressure in the ionization chamber and an extremely small beam-forming orifice and which would, nevertheless, provide a beam current equal to or greater than those afforded in the prior art. With such a gun it would be easy to maintain a hard vacuum in the utilization chamber because of the small pressure differential between it and the ionization chamber and because of the high resistivity of the gas leakage path between them through the small orifice.

Accordingy, it is an object of the present invention to devise an improved positive ion beam gun in which the gas in the ionization chamber may be at an extremely low pressure.

It is a further object of the present invention to devise an improved positive ion beam gun in which it is possible to produce a high current ion beam even though the orifice between the ionization chamber and the utilization device is extremely small.

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It is a further object of the present invention to devise an improved positive ion beam gun in which it is possible to produce a high current beam even though the orifice between the ionization chamber and the utilization device is extremely small and the gas pressure in the ionization chamber is extremely low.

It is a further object of the present invention to devise an improved positive ion beam gun which is capable of producing a beam of greatly increased current density.

Other features, objects and advantages of the present invention will be apparent to those skilled in the art from the following detailed description of the invention and from the drawing in which:

Figure 1 is a schematic cross-sectional represenation of an embodiment of the present invention;

Figure 2 is a representation of the configurations of certain equipotential surfaces which are established between a pair of electrodes of the embodiment of Fig. 1 during the operation thereof; and

Figure 3 is a schematic representation of another embodiment of the invention.

In general, according to the present invention, while they are in the ionization chamber the positive ions are focused into a conical beam with its apex (its point of greatest density) at the orifice leading to the utilization chamber; a substantial ion current is drawn through the orifice; and the ions are focused into a thin stream. For producing the ions and for focusing them while they are in the ionization chamber I use an ion-trap type of electron gun having a concave electron-emissive surface positioned with its center of curvature at the beam-forming orifice in an arrangement wherein a finite gas pressure exists and a substantially field-free zone is established between the cathode and the orifice. In this arrangement gas ions will be formed, and these ions and electrons which are emitted from the cathode will trap each other to effectively form coinciding beams which will be conical in shape because of the influence of the initial directions of electron emission, e. g., due to the shape of the cathode, and because of the absence of fields acting on the electrons and the ions. As to the negative field of the electron beam, it is cancelled by positive ions trapped within it. The large area of the cathode will result in a sizeable electron current and therefore the ionization chamber will afford an abundant source of positive ions even though the pressure of gas within it is very low. It will be seen that for certain purposes even the

extremely small pressure of the "residual gas" which remains after evacuation will be adequate. Moreover, the positive ions will be so positioned with respect to said orifice, i. e., crowded toward the apex of the cone, that large numbers of them will be attracted through it to form a high density beam even if the orifice is of extremely small size. It will be seen that outside of the ionization chamber ions which are drawn through the orifice will be focused into a beam by a novel and very strong electrostatic lens and that, in addition other ions will be formed externally of the chamber and will be added to the beam to augment its current.

The positive ion beam gun shown in Fig. 1 comprises at its left end, as shown in the drawing, a high current electron gun of a type which is described in co-pending application Serial Number 68,605 which is assigned to the assignee of the present application. This gun includes a cathode 10 which has the shape of a small segment of a sphere and is supported within an elongated envelope 11 with its concave side facing toward the far end thereof. The cathode is provided with a heater 12, which may be any one of a number of suitable types and may be supplied with heater current through a pair of leads 13 which are sealed through the envelope. An emissive coating 14 is applied to the concave side of cathode 10 The coating 14 faces toward an ionization chamber 15 through which a conically shaped beam of electrons, represented at 16, is to be directed. To the end that this beam may enter one side of the chamber 15 its wall 17 is formed with an electron-permeable central portion, i. e., a convex grid 18, which may be a woven wire mesh or similar open structure through which electrons may freely pass though the structure is effective to provide electrostatic shielding. In order that equipotential surfaces to be established between the concave coating 14 and the convex grid 18 will be spherically concentric with said coating, the grid 18 is formed in the shape of a segment of a sphere which is concentric with the coating. To permit the apex of the conical beam to pass out of the chamber 15 its opposite wall 19 is provided with a central orifice 20.

Due to the curvature of the emissive coating 14 and to the electrostatic lens provided between it and the convex grid 18, the emitted electrons will tend to converge toward the common center of curvature of these elements, i. e., toward the central orifice 20. As is known, ordinarily the sharpness of focus of an electron beam is adversely affected by the mutual repulsion of its electrons, i. e., by space charge effects, particularly if, as is preferred for the gun shown herein, it is a high-density low-velocity beam. However, as is set forth in the above-mentioned co-pending application, it is possible to cause entrapment of positive ions within the conically shaped beam so as to neutralize space charge effects and to attain precise focusing of the beam at the center of curvature of the cathode. The requirements for positive ion entrapment are a substantially field-free region in which the entrapment is to occur and gas molecules in the paths of the moving electrons to provide the ions. The relatively very small number of gas (air) molecules remaining after evacuation may suffice for an adequate supply of ions because a relatively considerable number of them will be ionized by the very large electron current provided by the type of cathode shown herein. (It should be remembered that ordinarily a beam which is to be brought to a point-focus, such as that in a kinescope, is composed of electrons emitted by a small-area or punctiform electron source.) In the preferred manner of operating an ion-trap electron gun, of a type corresponding to a combination of the elements herein which bear the reference numerals 10 to 20, to produce an unmodulated electron beam, all of the walls of the chamber 15 would be at the same static potential and this potential would be somewhat above, i. e., more positive than or less negative than, that of the cathode. While, as will be seen, this is also generally true in the operation of the present positive-ion gun, sometimes it may be advantageous to polarize the wall 19 at a slightly different potential than the other portions of the chamber 15. To this end the wall 19 is insulated from the rest of the chamber 15 by a glass insert 21 which should provide a gas-tight closure between this wall and the cylindrical side wall 22. An ion accelerating electrode 23, which may have the same general shape and size as the wall 19 is mounted to the right thereof by an insulating seal 24 similar to the insulating section 21 so that a very small centrally-located opening 25 is in direct alignment with the axis of the conical beam 16.

In a preferred circuit arrangement for operating the device of Fig. 1 the main portion of the chamber 15 is grounded, e. g., by grounding its side wall 22; the cathode 10 is connected to a source of negative direct poential 26; the wall 19 is connected to a source of potential 27 adjustable to values slightly above and slightly below ground potential; and the electrode 23 is connected to a source of negative direct potential 28 greater in magnitude than that provided at 26.

Fig. 2 represents the configurations of a plurality of equipotential surfaces 40—46 which may be established between the electrode 23 and the wall 19 by operating the ion gun in the circuit arrangement shown in Fig. 1, even if, during the operation of the gun, the wall 20 is at ground potential. It will be noted that the equipotential surfaces nearest to the wall 19 have very steep central craters some of which protrude through the orifice 20 so that fringing negative fields will exist within the chamber 15 near the orifice 20. As a result some of the ions trapped near the apex of the conical beam 16 will be drawn through the orifice 20. Thereafter they will be accelerated (primarily by the attraction of its lower-than-cathode negative potential) and they will be focused into a beam as shown at 29 (primarily by space charge effects to be described below).

In practice the depressed central portions of the equipotential surfaces 40—46 are so effective as an electrostatic lens that they focus the escaped positive ions, despite their relatively great masses, and direct them as a thin beam through the opening 25. This electrostatic lens is the resultant of several components. The first component results from the fact that the potential difference between the wall 19 and the electrode 23 will retard the forward-moving electrons so as to cause them to bunch in the apex of the conical beam while at the same time it will draw some positive ions therefrom through the orifice 20 so that a small amount of unneutralized negative-space-charge field will exist within the chamber 15 near said apex. This space charge component, besides aiding in causing ions to move out of the chamber 15 (through the orifice 20) and in focusing them, will tend to establish a drift of replacement ions down the cone toward its apex. Secondly, there is a component which is the result of distortions produced in the relatively flat equipotential surfaces of the accelerating field be-

tween the wall 19 and the electrode 23 by the presence of the orifice 20 in said wall. However, this may be a relatively minor component due to the small ratio of the diameter of the orifice to the diameter of this wall and/or to the distance to the electrode 23. Thirdly, the large numbers of unneutralized electrons which are carried through the orifice 20 by their kinetic energies (despite the repelling influence of the negative potential of the electrode 23) very materially contributes to this lens. As a matter of fact, this space charge field appears to be the most important component of all in-so-far as focusing the ion beam is concerned and it is probable that without it the relatively heavy ions could not be satisfactorily focused. However in practice it will be found that the relative importance of the third-mentioned component of the electrostatic lens can be varied over a considerable range by changing the size of the orifice 20, and/or the distance between the electrode 23 and the wall 19, and/or the potential difference between this wall and this electrode. As a matter of fact changes of these kinds which tend to increase the strength of the second-mentioned component of the electrostatic lens tend to cause a decrease in that of the third-mentioned component. For example, if the distance between the wall 19 and the electrode 23 is decreased and the potential difference between them is increased (so that the second component of the lens is increased), the electrons will encounter a much stronger retarding field so that fewer of them will escape through the orifice 20 and more of them will be reflected back through it whereby the third-mentioned component of the electrostatic lens will be reduced.

As was indicated above, there is a continuous drift of replacement ions moving down the cone 16 towards its apex due to the presence of some space charge field. Thus, provided new molecules of gas are continuously being ionized and trapped within the chamber 15, a relatively abundant supply of ions will be available, from the cone 16, for forming the beam 29. However the beam 29 also acquires large numbers of ions in the region between the wall 19 and the electrode 23. This is due to the fact that considerable gas ionization occurs in the portion of this region wherein large-order electron currents are moving (through a gaseous medium) from the output side of the orifice 20 to the outside surface of the wall 19 as shown at 30 in Fig. 1; that these ions will be accelerated toward the electrode 23 by its negative potential; and that they will be focused by the above-described electrostatic lens.

By proper adjustment of the potentials provided at 26 and 28, the ions may be brought to a sharp focus within the orifice 25 and to pass these through as a thin stream.

Whereas the ions upon leaving the chamber 15 are focused in the manner set forth above, the electrons are abruptly defocused, i. e., the electron beam "explodes." This is the result of several factors: (1) the number of positive ions which are drawn through the orifice 20 by the fringing field of the electrostatic lens is not large enough to neutralize the negative space charge of the large number of electrons which are carried through this same orifice by the kinetic energy originally imparted to them in moving from the cathode 18 to the grid 18 (it should be borne in mind that of the two cone shaped beams which coincide within the ionization chamber one, the electron beam, is moving and the other, the ion beam, is substantially static); (2) the gradient which is set up between the wall 19 and the electrode 23 for the purpose of attracting ions toward the utilization chamber will repel electrons and, due to the magnitude of this gradient, it will overcome their kinetic energies and turn them back; and (3) the electrostatic lens which acts to concentrate the positive ions has exactly the opposite effect on the negative electrons. Therefore the electrons travel paths such as those represented at 30.

In order to attain and maintain space charge neutralization while ion current is being drawn from the ionization chamber 15 it is essential that replacement ions be produced and entrapped at the same rate that the beam ions are withdrawn. In cases where it either is not essential for the utilization chamber to be under hard vacuum or where only a small-magnitude ion beam current is required, sufficient replacement ions may be produced by using an arrangement of the kind shown in Fig. 3 with only residual gas included in the envelope in the former cases and with more-than-residual gas included in the envelope in the latter cases.

In this arrangement, which represents an oscilloscope utilizing a positive ion beam rather than the usual electron beam, the cathode 18, the chamber 15, the wall 19 and the electrode 23 perform the same electrical functions as, and may be identical to, the corresponding elements of the Fig. 1 embodiment. In this embodiment, however, the insulating section 21 and the insulating seal 24 are omitted and the physical structure is otherwise modified so that a unitary evacuated envelope 50, which surrounds and encloses all of the gun elements, takes the place of the composite envelope of Fig. 1 which incorporates into its wall structure portions of the metallic electrode system. The envelope may be under hard vacuum so that its only gas content is residual gas or it may contain a more substantial amount of gas. In the latter case consideration should be given to the usual design problems which this entails such as avoiding excessive ion bombardment of the emissive cathode coating and excessive oxidation of the incandescent heater. In Fig. 3 a fluorescent screen is represented at 51 and ion-beam deflection means at 52. In the operation of this embodiment ions will be projected onto screen 51 and deflected over its surface by the application of voltages to the deflection means 52 (or of currents to appropriate corresponding magnetic deflection means). After they strike the screen 51 the ionized molecules will recombine with electrons and due to their thermal velocities they eventually will find their way back to the space surrounding the ionization chamber and into the chamber itself. This kind of operation is possible due to the absence of a gas-tight seal between the wall 19 and the beam-output side of the envelope and it is aided by the absence of a seal between this wall and the side wall of the chamber 15.

The embodiment of Fig. 1 is to be preferred for certain uses, such as in a cyclotron, a mass spectrograph or a linear accelerator, wherein it is essential for the utilization chamber to be under hard vacuum, while at the same time larger ion-beam currents are needed than can be sustained by the replacement ions which can be produced from residual gas. In its use in any of these three devices the ion beam 29 will be projected from the opening 25 into a utilization chamber 31 which preferably will be maintained under hard vacuum by continuous pumping.

The utilization chamber 31, as shown in Fig. 1, comprises a flange 32 by which this ion gun either may be made a part of a device requiring an ion beam or may be attached thereto. Block 33 represents any suitable apparatus for initial and/or continuous vacuum pumping of the utilization chamber, and, where required (as, for example, where the device is to be operated in a particular manner to be described below) of the chamber 15 as well. Provision is made to sustain large ion beam currents by introducing gas molecules at an appropriate rate into the chamber 15 where some of them will become "replacement ions" (by becoming ionized and entrapped in the conical beam 16). Since, as is known, this rate of replacement of ions is controllable by the molecular density (gas pressure) within the ionization chamber, enough gas should be introduced so that the required pressure will be maintained despite the significant continual loss of gas molecules through the orifice 20 (some of them being ionized molecules which are electrically attracted through the orifice toward electrode 23 and some of them being either ionized or unionized molecules which are urged out of the orifice by the pressure differential on opposite sides of the wall 19). In adding gas so as to maintain space charge neutralization one should avoid adding so much that a self-sustained gaseous discharge will be started between the cathode 10 and the grid 18. As is known, if this occurs the cathode will be stripped and the grid wires may be overheated. To permit the controlled replacement of gas molecules into the ionization chamber the ion gun shown in Fig. 1 includes a source of gas 34 and a metering means 35 for controlling the rate at which gas is transferred from the source 34 into the chamber 15. It also includes a valve 36 by manipulation of which the gas may be metered into the region between the wall 19 and the electrode 23 instead of into the chamber 15 for operating the device in the particular manner referred to above.

Although generally satisfactory operation is reliably obtainable if the wall 19 is maintained at exactly the same potential as the rest of the chamber 15, I have found it advantageous to provide means, e. g., as shown in Fig. 1, whereby it can be slightly varied in potential with respect thereto. Due to the fringing field which extends into the chamber 15 through the opening 20 its interior is not completely and uniformly field-free and therefore complete and uniform space charge neutralization and exact conical focusing are not always attained when the entire chamber 15 is at the same potential. The possibility of varying the potential of the wall 19 over a very narrow range of potentials all of which are very close to that of the rest of the chamber affords an additional adjustable parameter which in practice makes it easier to optimize the density and focus of the ion beam.

If desired the embodiment shown in Fig. 1 may be modified by manipulating the valve 36 to connect the output of the metering means 35 to the section of the composite envelope (shown in Fig. 1) which is located between the wall 19 and the electrode 23 instead of to the chamber 15 and by opening the stop cock 37 to connect the vacuum pump to the chamber 15 as well as to the utilization chamber 31. In such an arrangement a hard vacuum would be maintained not only in the utilization chamber but also in the chamber 15 and in the region to the left of the wall 17 wherein the cathode is mounted. This would be advantageous from the standpoint of protecting the emissive coating 14 and the heater 12. In an arrangement of this type it would be desirable to select a proper size for the orifice 20, a proper spacing between the wall 19 and the electrode 23, and a proper potential difference between these elements to avoid drawing positive ions from the apex of the conical beam 16 at a higher rate than replacement ions can be generated from residual gas. (In this connection, it should be borne in mind that there will always be some residual gas, i. e., a significant number of new gas molecules will be exuded from the materials comprising the walls of the envelope even if a very hard vacuum is maintained—such as 10^{-8} atmospheres—and even if at the same time ionized gas molecules are continuously drawn out through orifice 20.) Obviously no corresponding problem is presented if large numbers of electrons are continuously escaping through the orifice 20, since they may readily be replenished by emission from the large-area cathode 10. Within rather wide limits one may vary the electron current projected through the ionization chamber so as to control the production of ions in the region to the right of the wall 19 and thereby to control the ion beam current, e. g., the electron current may be varied by using different types of material for the emissive coating 14 and/or by varying the operating temperature of the cathode, and/or by varying the accelerating field between the cathode and the grid 18. This field should in no case be lower than the ionizing potential of the gas in the chamber 15 and in no case high enough to start a self-sustained discharge. I have found that the ion beam current can be made to attain a fairly high value outside of the ionization chamber even if only a light ion beam is drawn through the orifice 20 provided a substantial electron current is flowing and provided a substantial gaseous content is introduced into the region between the wall 19 and the electrode 23. In no case should so much gas be introduced into this region that the electron beam space charge will become neutralized in spite of the ion-sweeping electrostatic field in this region. As indicated above, the electrons represented at 30 will continually produce fresh ions as represented at 38 in Fig. 2; these ions will be accelerated toward the electrode 23 by its negative potential and they will be strongly focused by the space charge field of the electrons at 30. In fact because of this the device shown herein would be operative as an ion beam source even if no ions were provided from the chamber 15, e. g., even if the portion of the device to the left of the wall 19 were merely a source of a very dense electron beam.

From the foregoing it is apparent that due to the sharp focus to which the conical beam 16 is brought by space charge neutralization and to the resultant concentration of ions at the apex of the cone, a relatively very substantial ion current can be drawn through an orifice 20 of very small size; that in addition, it is possible to make this orifice even smaller due to the fact that ions are added to the beam outside of the utilization chamber; that due to the large electron current the considerable ion replacement required for the continuance of neutralization is attained even for very light gas pressures; that in addition, due to unexpectedly effective focusing of the ion beam 29 the opening 25 may be made even smaller than the orifice 20; and that (as a result of the possibility of using in combination a low

gas pressure, a small orifice, and a small opening) it is relatively easy to maintain the utilization chamber under hard vacuum.

If desired, for example in order to conserve a rare gas being tested in a mass spectrograph or to avoid contamination of the air by a noxious gas, the arrangement of Fig. 1 may be modified to provide a closed gas circuit by connecting the output of the vacuum pump to the input of the metering means 35.

While certain specific embodiments have been illustrated and described, it will be understood that various changes and modifications may be made therein without departing from the spirit and scope of the invention.

What I claim is:

1. Apparatus for producing a beam of ions comprising: a substantially field-free ionization chamber having a large electron permeable area in one of its walls and a small beam-defining orifice in its opposite wall; a gaseous medium in said chamber; means including a large-area concave emissive surface facing said electron-permeable area for projecting electrons from said surface into said chamber in such directions that they tend to form a thick electron beam having a sharp apex at said orifice whereby in the operation of the apparatus positive ions are produced in said chamber by ionization of said medium, and are entrapped by electrons therein neutralizing their space charge to allow said electron beam to be formed with said apex; means for drawing out of said chamber through said orifice positive ions entrapped in said apex and means for focusing said withdrawn ions into a thin beam.

2. Apparatus for producing a beam of ions comprising means for establishing a field-free ionization region including a first conductive wall having a large electron-permeable area and, on the opposite side of said region from it, a second wall having a small beam-defining orifice in alignment with said area; a gaseous medium in said region; means including a large-area concave emissive surface facing said electron-permeable area for projecting electrons from said surface into said region in such directions that they tend to form a thick electron beam having a sharp apex at said orifice whereby in the operation of the apparatus positive ions are produced in said region by ionization of said medium and are entrapped by electrons therein neutralizing their space charge to allow said electron beam to be formed with said apex; means for drawing out of said region through said orifice positive ions entrapped in said apex; means for focusing said withdrawn ions into a thin beam; and at least a portion of the wall structure of an ion-beam utilization chamber having a small opening so aligned with said orifice that in the operation of the apparatus said thin beam is projected through it into said utilization chamber.

3. Apparatus for producing a beam of ions comprising means for establishing a field-free ionization region including a first conductive wall having a large electron-permeable area and, on the opposite side of said region from it, a second wall having a small beam-defining orifice in alignment with said area; a gaseous medium in said region; means including a large-area concave emissive surface facing said electron permeable area for projecting electrons from said surface into said region in such directions that they tend to form a thick electron beam having a sharp apex at said orifice whereby in the operation of the apparatus positive ions are produced in said region by ionization of said medium and are entrapped by electrons therein neutralizing their space charge to allow said electron beam to be formed with said apex; means for drawing out of said region through said orifice positive ions entrapped in said apex; means for focusing said withdrawn ions into a thin beam; and means for continuously metering additional molecules of the gaseous medium into said ionization region whereby replacement ions will be produced and entrapped to sustain continued withdrawal of ions for forming the thin beam.

4. Apparatus for producing a beam of ions comprising: a substantially field-free ionization chamber having a relatively large electron-permeable area in one of its walls and a relatively small beam-defining orifice in its opposite wall; a gaseous medium in said chamber; means including a large-area concave emissive surface facing said electron-permeable area for projecting electrons from said surface into said chamber in such directions that they tend to form a thick electron beam having a sharp apex at said orifice whereby in the operation of the apparatus positive ions are produced in said chamber by ionization of said medium, become entrapped by electrons therein and neutralize the electron space charge to allow said electron beam to be formed with said apex; means for drawing out of said orifice positive ions entrapped in said apex; at least a portion of an ion beam utilization chamber including a wall structure having a small opening in predetermined alignment with said orifice; means for focusing said withdrawn ions into a thin beam in a region between said opposite wall of the ionization chamber and said wall structure and for directing it so that it will be projected through said opening into the utilization chamber; an envelope structure so joined to one side of said wall structure as to constitute a closure which is entirely gas-tight except for said opening; and the opposite side of said wall structure being on the inside of said portion of a utilization chamber.

5. Apparatus for producing a beam of ions comprising: a substantially field-free ionization chamber having a relatively large electron-permeable area in one of its walls and a relatively small beam-defining orifice in its opposite wall; a gaseous medium in said chamber; means including a large-area concave emissive surface facing said electron-permeable area for projecting electrons from said surface into said chamber in such directions that they tend to form a thick electron beam having a sharp apex at said orifice whereby in the operation of the apparatus positive ions are produced in said chamber by ionization of said medium, become entrapped by electrons therein and neutralize the electron space charge to allow said electron beam to be formed with said apex; means for drawing out of said orifice positive ions entrapped in said apex; at least a portion of an ion beam utilization chamber including a wall structure having a small opening in predetermined alignment with said orifice; means for focusing said withdrawn ions into a thin beam in a region between said opposite wall of the ionization chamber and said wall structure and for directing it so that it will be projected through said opening into the utilization chamber; an envelope structure so joined to one side of said wall structure as to constitute a closure which is entirely gas-tight except for said opening; the opposite side of said wall struc-

ture being on the inside of said portion of a utilization chamber; and means for continuously metering molecules of said gaseous medium into said closure.

6. Apparatus for producing a beam of ions comprising: a substantially field-free ionization chamber having a relatively large electron-permeable area in one of its walls and a relatively small beam-defining orifice in its opposite wall; a gaseous medium in said chamber; means including a large-area concave emissive surface facing said electron-permeable area for projecting electrons from said surface into said chamber in such directions that they tend to form a thick electron beam having a sharp apex at said orifice whereby in the operation of the apparatus positive irons are produced in said chamber by ionization of said medium, become entrapped by electrons therein and neutralize the electron space charge to allow said electron beam to be formed with said apex; means for drawing out of said orifice positive ions entrapped in said apex; at least a portion of an ion beam utilization chamber including a wall structure having a small opening in predetermined alignment with said orifice; means for focusing said withdrawn ions into a thin beam in a region between said opposite wall of the ionization chamber and said wall structure and for directing it so that it will be projected through said opening into the utilization chamber; an envelope structure so joined to one side of said wall structure as to constitute a closure which is entirely gas-tight except for said opening; the opposite side of said wall structure being on the inside of said portion of a utilization chamber; and said opposite wall of the ionization chamber being sealed across walls of said envelope structure so that said orifice is the only opening between the ionization chamber and said region in which the thin beam is focused.

7. Apparatus for producing a beam of ions comprising: a substantially field-free ionization chamber having a relatively large electron-permeable area in one of its walls and a relatively small beam-defining orifice in its opposite wall; a gaseous medium in said chamber; means including a large-area concave emissive surface facing said electron-permeable area for projecting electrons from said surface into said chamber in such directions that they tend to form a thick electron beam having a sharp apex at said orifice whereby in the operation of the apparatus positive ions are produced in said chamber by ionization of said medium, become entrapped by electrons therein and neutralize the electron space charge to allow said electron beam to be formed with said apex; means for drawing out of said orifice positive ions entrapped in said apex; at least a portion of an ion beam utilization chamber including a wall structure having a small opening in predetermined alignment with said orifice; means for focusing said withdrawn ions into a thin beam in a region between said opposite wall of the ionization chamber and said wall structure and for directing it so that it will be projected through said opening into the utilization chamber; an envelope structure so joined to one side of said wall structure as to constitute a closure which is entirely gas tight except for said opening; the opposite side of said wall structure being on the inside of said portion of a utilization chamber; said opposite wall of the ionization chamber being sealed across walls of said envelope structure so that said orifice is the only opening between the ionization chamber and said region in which the thin beam is focused; and including means for continuously metering molecules of said gaseous medium into said closure.

8. Apparatus for producing a beam of ions comprising: a substantially field-free ionization chamber having a relatively large electron-permeable area in one of its walls and a relatively small beam-defining orifice in its opposite wall; a gaseous medium in said chamber; means including a large-area concave emissive surface facing said electron-permeable area for projecting electrons from said surface into said chamber in such directions that they tend to form a thick electron beam having a sharp apex at said orifice whereby in the operation of the apparatus positive ions are produced in said chamber by ionization of said medium, become entrapped by electrons therein and neutralize the electron space charge to allow said electron beam to be formed with said apex; means for drawing out of said orifice positive ions entrapped in said apex; at least a portion of an ion beam utilization chamber including a wall structure having a small opening in predetermined alignment with said orifice; means for focusing said withdrawn ions into a thin beam in a region between said opposite wall of the ionization chamber and said wall structure and for directing it so that it will be projected through said opening into the utilization chamber; an envelope structure so joined to one side of said wall structure as to constitute a closure which is entirely gas-tight except for said opening; the opposite side of said wall structure being on the inside of said portion of a utilization chamber; said opposite wall of the ionization chamber being sealed across walls of said envelope structure so that said orifice is the only opening between the ionization chamber and said region in which the thin beam is focused; and including means for indirectly metering molecules of said gaseous medium into said region in which the thin beam is focused by directly metering it into said utilization chamber whereby some of the molecules will reach said region through said orifice.

9. Apparatus for producing a beam of ions comprising: a substantially field-free ionization chamber having a relatively large electron-permeable area in one of its walls and a relatively small beam-defining orifice in its opposite wall; a gaseous medium in said chamber; means including a large-area concave emissive surface facing said electron-permeable area for projecting electrons from said surface into said chamber in such directions that they tend to form a thick electron beam having a sharp apex at said orifice whereby in the operation of the apparatus positive ions are produced in said chamber by ionization of said medium, become entrapped by electrons therein and neutralize the electron space charge to allow said electron beam to be formed with said apex; means for drawing out of said orifice positive ions entrapped in said apex; at least a portion of an ion beam utilization chamber including a wall structure having a small opening in predetermined alignment with said orifice; means for focusing said withdrawn ions into a thin beam in a region between said opposite wall of the ionization chamber and said wall structure and for directing it so that it will be projected through said opening into the utilization chamber; an envelope structure so joined to one side of said wall structure as to constitute

a closure which is entirely gas-tight except for said opening; the opposite side of said wall structure being on the inside of said portion of a utilization chamber; said opposite wall of the ionization chamber being sealed across the walls of said envelope structure so that said orifice is the only opening between the ionization chamber and said region in which the thin beam is focused; and including means for metering molecules of said medium directly into said region in which the thin beam is focused and means for continuously evacuating the ionization chamber.

10. Apparatus for producing a beam of ions comprising: a substantially field-free ionization chamber having a relatively large electron-permeable area in one of its walls and a relatively small beam-defining orifice in its opposite wall; a gaseous medium in said chamber; means including a large-area concave emissive surface facing said electron-permeable area for projecting electrons from said surface into said chamber in such directions that they tend to form a thick electron beam having a sharp apex at said orifice whereby in the operation of the apparatus positive ions are produced in said chamber by ionization of said medium, become entrapped by electrons therein and neutralize the electron space charge to allow said electron beam to be formed with said apex; means for drawing out of said orifice positive ions entrapped in said apex; at least a portion of an ion beam utilization chamber including a wall structure having a small opening in predetermined alignment with said orifice; means for focusing said withdrawn ions into a thin beam in a region between said opposite wall of the ionization chamber and said wall structure and for directing it so that it will be projected through said opening into the utilization chamber; an envelope structure so joined to one side of said wall structure as to constitute a closure which is entirely gas-tight except for said opening; the opposite side of said wall structure being on the inside of said portion of a utilization chamber; said opposite wall of the ionization chamber being sealed across walls of said envelope structure so that said orifice is the only opening between the ionization chamber and said region in which the thin beam is focused; and including means for continuously evacuating the ionization chamber.

11. Apparatus for producing a beam of ions comprising an envelope containing: means including a wall with an area which is permeable to charged particles for producing a field-free space, an atmosphere containing gas molecules within said space, means for producing a beam of electrons in a region outside of said space, means for accelerating said beam externally of said space to direct it through said space for ionizing the gas molecules, and other means within said envelope for drawing ions out of said space and forming them into a focused beam of small transverse section and for directing said ion beam along a predetermined path.

12. An ion-gun comprising an envelope containing gas molecules, within the envelope a chamber surrounding a substantially field-free ionization space and having two sides which are permeable to charged particles, means for directing convergent electrons through one of said sides of the chamber to produce a concentration thereof near the inside surface of the other, said electrons being projected through said space with sufficient energy to ionize molecules of said gas therein whereby a conical beam of positive ions will be entrapped within the portion of said electron beam inside of said space with a large number of the entrapped ions concentrated near the apex of said entrapped beam, means for drawing ions from said apex to a region outside of said chamber through said one side thereof, and means for focusing withdrawn ions into a thin beam and projecting them along an axis in said region.

13. An ion gun as in claim 12 which further comprises means for controlling a further ionization of gas molecules which is caused in said region outside of said chamber by the electron beam as it emerges from said one side of the chamber, and in which said means for focusing is effective to focus both ions which are withdrawn from said space and also ions produced in the region outside of said chamber.

14. In an ion gun an ion-focusing electron-lens arrangement comprising: an electron-permeable electrode; gun means for projecting a high density electron beam along an axis through said electrode from one of its sides to the other; an ionizable gaseous atmosphere, adjacent said one side of said electrode and surrounding the path of said beam to be exposed thereat to ionization by electron collisions, whereby positive ions will be entrapped by the field of the beam; means adjacent said other side of said electrode for deflecting the electrons of said beam in different radial directions outward from said axis to spread the field of their electron space charge symmetrically thereabout; and means adjacent said other side of the electrode for drawing ions along said axis through the electrode and thereafter through said electron space charge to be focused thereby.

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