

Feb. 28, 1950

L. D. P. KING
ION SOURCE

2,498,841

Filed June 1, 1945

3 Sheets-Sheet 1

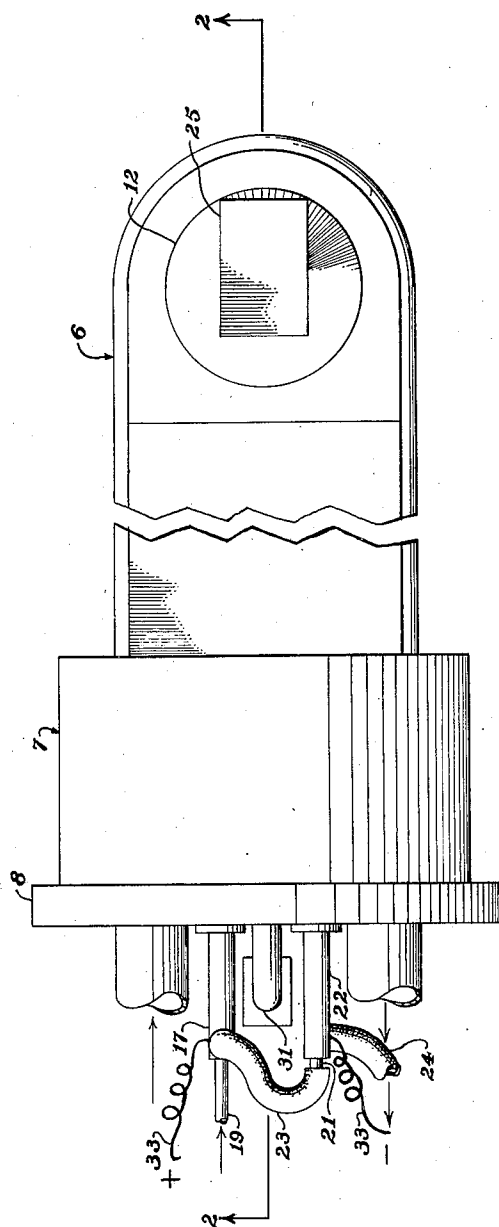


Fig. 1

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3 Sheets-Sheet 2

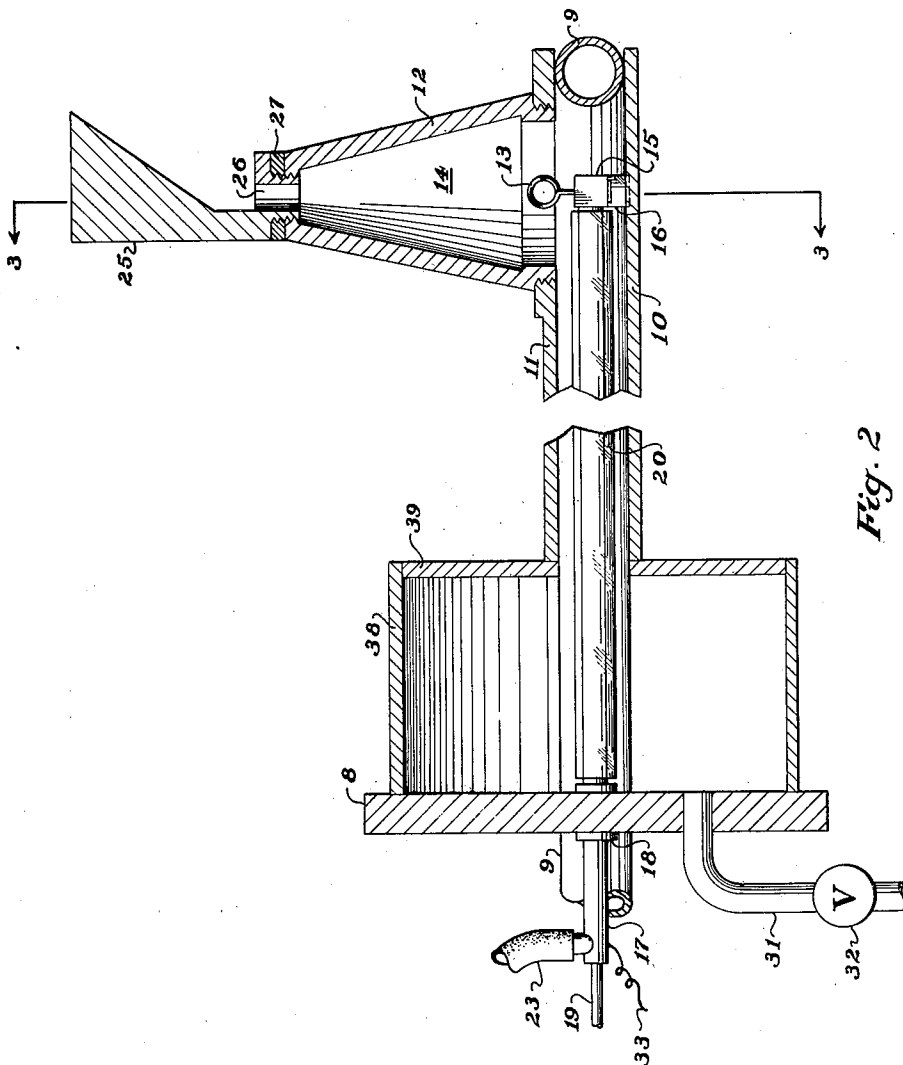


Fig. 2

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3 Sheets-Sheet 3

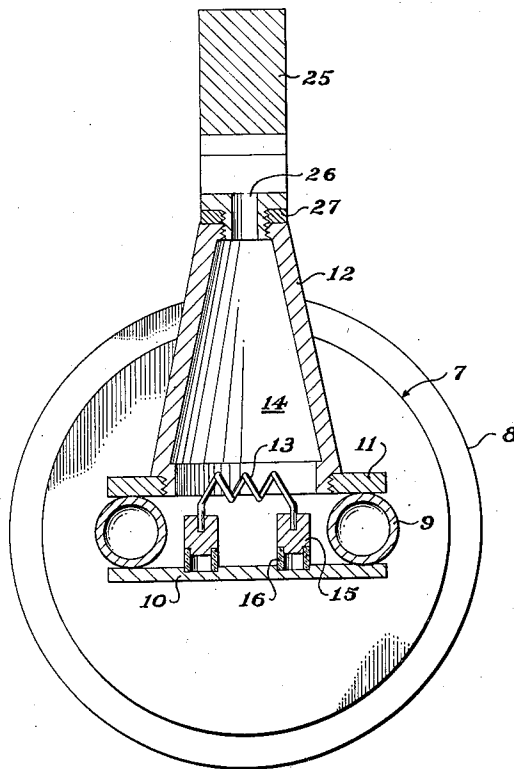


Fig. 3

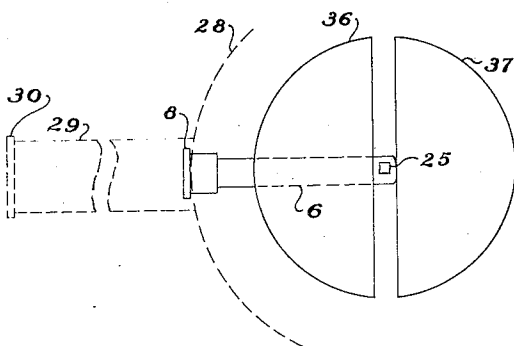


Fig. 4

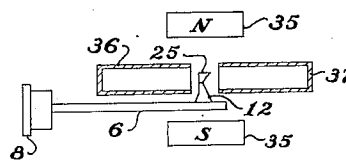


Fig. 5

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UNITED STATES PATENT OFFICE

2,498,841

ION SOURCE

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3 Claims. (Cl. 250—84)

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This invention relates to a gaseous electric discharge apparatus and more particularly to apparatus capable of producing in quantity a substantially continuous stream of ions to be employed in a charged particle accelerating device such as a cyclotron or the like. More particularly, the electric discharge apparatus of the present invention is designed primarily for readily producing a substantially continuous stream of gaseous ions under critical conditions.

In normal accelerating procedures it is found desirable and/or necessary to accelerate as many of the desired ions as possible in order to reduce the operating time of the accelerating device with resulting savings in the power expended. Furthermore, when inefficient ion sources are utilized, gases are pumped through the accelerating devices without producing ions causing interference with the proper operation of the device in addition to the waste involved in the pumping work and in the non-productive use of expensive raw materials.

For example, the importance of the considerations mentioned above may be gauged from such nuclear reactions as are brought about by bombardment in a cyclotron or the like by accelerated deuterium and/or tritium ions. Deuterium ions are extremely important among the many bombarding particles used for transmutation purposes. The gas, however, is costly and the pumping of large volumes in order to attain the necessary ion beam intensity at the target (i. e., the beam current as measured in microampere units) renders the problem prohibitive from the standpoint of expense and equipment when ion source apparatus constructed in keeping with the teachings and principles of the prior art are followed. Similarly, atomic tritium ions, that is ions of the hydrogen isotope of mass 3, are extremely costly and rare since the isotope can only be obtained in concentrations of the order of 0.025% after careful separation. Studies of the nuclear changes brought about by bombardment by tritium ions are important, for example, to fully understand the nature of the reaction produced by the bombardment of deuterium with deuterium ions and the use of this latter reaction as a means for supplying a substantial number of neutrons such as may be useful for example in initiating and/or producing a neutron chain reaction. Since such nuclear processes are infrequent in laboratory occurrence, it is necessary to have higher beam currents at the target zones and a source that will function without interruption to produce such a beam in order to obtain a full and complete

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understanding of the various factors involved.

Illustrative of the methods previously used when the gas pressure in a cyclotron is maintained at about 10^{-4} millimeters of mercury (as it must be to prevent electrical discharge within the device) the introduction of heated filament at the central region of the device and adjacent to the entrance apertures of the electrodes or "D's" of the device was found to be sufficient to give beam intensities of from one to ten microamperes. Higher intensities (e. g. of the order of one hundred microamperes) could be obtained by lengthening the filament and increasing the vertical height of the apertures. However, such a procedure required a longer magnetic gap in the cyclotron and consequently involved a greater power input to obtain the required field intensities. More compact and efficient ion sources have been designed to overcome the deficiency just mentioned as well as to correct the divergent nature of a beam produced by an elongated filament. Many such sources were of the electric discharge type and included a cathode and an anode contained within an enclosed chamber, means for the introduction of a gas into the chamber, means for establishing an arc between the cathode and anode, and a capillary passage aligned with the entrance to the accelerating apparatus through which the gas passed and was ionized. By forming the arc between an electrode and the capillary passage as is disclosed in Slepian U. S. Patent 2,285,622 or by constructing the arc discharge in a passage which communicates with the capillary outlet, it was found possible to increase the ion production in such electric discharge sources. However, the increased ion production was accompanied by a continuation of the divergent nature of the beam requiring the combination of focusing parameters or electro-static lenses with the source. Furthermore, while such studies in electron optics and the like have advanced, they have failed to supply a flexible method or apparatus for producing intense positive ion beams, more particularly, an ion source that is readily adaptable to supply ions of various gases, having different characteristics, as deuterium, helium, tritium and/or the like.

From the above, it becomes apparent that the present invention has for an object the provision of a simple compact method and means for producing a substantial number of gaseous ions.

Another object is to provide a method of focusing an intense ion beam.

It is a further object to provide flexible focusing means which will also serve to effect a pre-

liminary separation and/or elimination of undesirable ions from an accelerating device.

It is still further object of this invention to provide an electric discharge type of ion source which will operate for considerable periods of time without burning out or suffering from other effects engendered by high current densities required for operation.

Other objects will appear from the following detailed description of the invention.

The objects mentioned are attained by the present invention by establishing a collimated beam of fast moving electrons which is directed into a capillary opening in an otherwise sealed closure or chamber into which the gas to be ionized is introduced at a pressure at least in excess of the pressure maintained at the outside of the chamber and adjacent to the outward end of the capillary opening or passage. As the gas moves out of the chamber, by reason of the pressure differential, the atoms are bombarded in the capillary by the collimated electrons and are ionized and given an outward acceleration by an electric field maintained outside the source. Now, by placing a deflecting surface in the path of the outwardly directed and accelerated stream of ions and causing the stream to impinge upon that surface, it has been discovered that if the diameter of the capillary opening of the chamber and the angle which the incident ion beam makes with that surface are properly chosen, the desired ions can be directed in a substantially sharply focused beam into the accelerating device and a large number of undesired ions can be deflected away from the entrance of the accelerating device.

In order to further the understanding of this invention, reference is made to an illustrative embodiment which is only given by way of example and should not be deemed a limitation hereon. The principles of the invention are applied to the construction of an ion source of the electric discharge type for use in a cyclotron although as will be more apparent from the detailed description hereinafter set out, a similar or equivalent structure may be used for producing ions for other charged particle accelerating devices or other uses. In the drawings, which are made part of this specification

Figure 1 shows in plan an electric discharge type ion source constructed according to the principles of this invention.

Figure 2 is an elevational view partly in cross-section taken on the line 2—2 in Figure 1 which shows the position of the filamentary electron emissive cathode used in this embodiment.

Figure 3 is another sectional view of the ion source taken on the line 3—3 in Figure 2.

Figure 4 is a schematic plan representation showing the position of the ion source in a cyclotron structure.

Figure 5 is a schematic elevation showing the vertical disposition of the ion source in relation to the accelerating device.

Turning now to the drawings, the ion source embodying the principles of this invention consists of an elongated flat source housing 6 which communicates with an enlarged hollow cylindrical portion 7 made integral with a header plate 8 by soldering or in any other suitable way that will result in an air tight seal. The header plate 8 extends beyond the cylindrical section 7 to form a circumferential flange which abuts against a cooperating raised portion or boss on the outer wall of the cyclotron and thereby acts to properly

position the source in relation to the cyclotron electrodes as will be more fully explained hereafter.

The flat portion 6 of the housing is preferably constructed in the manner indicated more clearly in Figure 2. A copper tube 9 having an inside diameter of about three-eighths of an inch and a wall thickness of about one-thirty-second of an inch is bent in the shape of an elongated U. The straight portions of the bent tube 9 should be sufficiently long to permit proper positioning of the source, their length depending upon the diameter of the cyclotron housing and allowance of a sufficient excess for the connection of inlet and outlet water pipes, to the portion of the tubes that extend beyond the header 8. Copper strip 10 which is about one-eighth of an inch thick is soldered to the tube 9 to form the bottom of the flat portion 6 and copper strip 11 is soldered to the tube 9 to form the top. The strip 11 is one-eighth of an inch in thickness for most of its length but has a heavier portion, for example, about one-quarter of an inch in thickness, which is drilled and threaded to accommodate the hollow conical copper arc chamber housing 12 in heat conducting relationship. Now if the strips 10 and 11 are properly soldered to the tube 9 so that gas leakage is prevented a flat housing will be formed which has a conical arc chamber housing removably inserted in gas tight relationship therewith, in the upper side. It might also be noted at this point that it is preferred to thread the conical chamber housing 12 externally as is shown in Figures 2 and 3 to cooperate with an internally threaded opening in the strip 11 because upon heating of the walls of chamber housing 12 by the action of the arc, expansion will tend to close the contacting threads and thus tend to prevent gas leaks during operation. Furthermore, it is found desirable to provide a shoulder on the arc chamber 12 to abut against the strip 11 to provide maximum heat transfer across the interface of the two parts.

Referring now to Figures 2 and 3 of the drawings wherein certain features of the invention are shown in more detail, it will be noted that the cathode 13 is a helix of a suitable refractory metal wire, preferably tungsten, and is supported within the arc chamber 14 by having its ends secured within drilled openings in a respective one of the copper blocks 15 by set screws, for example. The copper blocks 15 are in turn supported in spaced relationship by quartz, Mycalex or other insulators 16 tightly seated in recesses provided therefor in bottom strip 10. Alternatively, the supporting blocks 15 may be insulated from the strip 10 by sheets of mica or other heat resistant insulating material. Hollow electrical conductors 17 and 22 are soldered to the blocks 15 and extends through the flat chamber 6 and are insulated and sealed from the header plate 8 by the bushings 18. An inner squirt tube 19 supported coaxially and concentrically within the outer conductor 17 permits a liquid coolant to be circulated through the squirt tube 19 and returned through the annular space between the squirt tube 19 and the hollow conductor 17. The outward end of conductor 17 is sealed with squirt tube 19 by soldering for example, thus permitting the circulating coolant to be tapped from the conductor 17 at some suitable place, for example, as is shown in Figure 1. The provision for the circulation of a liquid coolant to the blocks 15 permits the removal of heat from the ends of the filamentary cathode where they contact the

blocks 15 and thus minimizes the deterioration of the filament.

Since a suitable heater voltage must be applied to the filamentary cathode and further since an accelerating voltage for electrons must be applied between the filamentary cathode and the arc chamber walls as an anode for causing the electron emission of the filament to bombard the gaseous atoms within the source it is apparent that the conductors 17 and 22 must be insulated from each other. As has been noted they are each insulated and sealed from the header plate 8 by the bushing 18. Glass wool or quartz tube sleeves 20 fitted over each of the conductors 17 and 22 prevent a discharge between the conductors within the source housing.

It will be seen from the foregoing that provision is made for a completely water cooled ion source housing structure in which are disposed water cooled conductors for supplying a heater voltage to a filamentary cathode disposed within such housing. It has been found satisfactory to connect the liquid coolant circulating systems formed by the squirt tubes 19 and 21 and the conductors 17 and 22 respectively in series as is shown in Figure 1. In other words, a liquid coolant is led into the squirt tube 19 through a suitable hose connection to a source of such liquid coolant, and circulates to the block 15 and returns through the annular space between the squirt tube and the conductor 17 and is led therefrom through rubber hose connection 23 to squirt tube 21. Rubber tubing 24 carries the discharged coolant from conductor 22 to any convenient discharge point. Similar provisions of supply and discharge are made for circulating a coolant through tube 9 though not shown in the drawings.

A gas, the ions of which are desired is introduced into the source through the tube 31 which is soldered or otherwise rigidly attached to header plate 8. A flexible hose or the like is connected to the tube by clamping or by other well known coupling devices, and extends to the outside of the cyclotron structure. Metering devices such as flow meters, pressure meters and the like may be used to determine the amount of gas being introduced into the source, and suitable regulating valves such as indicated at 32 disposed outside the cyclotron may be used to control these amounts.

Returning now to a consideration of the arc chamber 14 as defined by the conical housing 12 and more particularly to the view shown in Figure 2, it will be noted that the apex of the housing 12 is drilled and threaded to receive a copper deflecting member 25 which has a suitable capillary passage 26 drilled in it to permit communication between the arc chamber 14 and the accelerating device. A lock nut 27 is provided so that the direction of deflection might be adjustable by adjustment of the position of member 25 (i. e. by rotation about the vertical axis of capillary 26) and the heat transfer between the member 25 and housing 12 kept at a maximum.

The cylindrical section 7 of the housing comprises the header plate 8, a tubular section 38 of copper tubing, and a sealing transition plate 39, all soldered together in gas tight relationship. Openings are provided in the sealing plate 39 and header plate 8 to permit the legs of the tube 9 to extend therethrough. The entire housing may then be sealed by soldering the strips 10 and 11 to the plate 39 and suitably sealing the tube 9 at the plate 39 and at the header plate 8. A gas passage is also provided in sealing plate 39 to permit communication between the spaces within

the cylindrical section 7 and within the flat portion 6 and passage of the gas, the ions of which are desired, from the supply container to the arc chamber.

In operation of a cyclotron with a source of the type described, the outer housing 28 (see Figure 4) has an opening through which the source is inserted to the position shown. To permit insertion of the source or its removal from the housing 28 without destroying the vacuum conditions existing therein, it has been found desirable to employ a substantially cylindrical housing or air-lock 29 having a sealing plate 30 attached to the outwardly extending end. A gate valve, not shown, is interposed between the air-lock 29 and the housing 28. When the source is ready for use with the gate valve in closed position, the source is inserted into the air-lock 29 which is then attached to the outer side of the valve by a multiplicity of bolts. The air-lock may then be evacuated and the gate valve opened. A rod which engages a threaded opening in header 8 and extends through a suitable sealing bushing integral with sealing plate 30 may then be used to push the ion source into a position within the cyclotron structure such that the desired ions are properly directed into the accelerating electrodes 36 and 37 (see Figures 4 and 5). The air-lock 29 may then be removed leaving the source in sealed relationship with the boss on the housing 28 and the necessary liquid coolant and gas connections made for operation.

Now using an ion source such as has been described, in a cyclotron operation in which, for example, tritium ions are desired as the bombarding particles, it was found that highly satisfactory results could be obtained whereas the use of previously designed ion sources resulted in failure. For this disintegrating operation, which involved the use of a gaseous mixture containing 0.025% of tritium atoms which in turn was diluted in ordinary tank hydrogen gas, in a ratio of one part of the tritium concentrate to one thousand parts of tank gas, the capillary opening 26 in the deflecting member 25 was about 0.140 inch in diameter and the angle the deflecting surface made with the vertical axis of the capillary was about thirty-five degrees. The overall height of the source at the inwardly extended end was about two inches, the beam being deflected into the cyclotron electrode 37 on a horizontal line substantially at the center of that electrode. The cyclotron was a thirty-seven inch type thus the overall length of the source housing was of the order of nineteen inches.

The source was inserted into the cyclotron housing using the air-lock procedure explained above, the pressure in the cyclotron being maintained at about 10^{-5} millimeters of mercury. The switches (not shown) controlling the current input to the filament through wires 33 were closed and the filament heated slowly to an electron emissive temperature, the necessary current control being maintained by a variable autotransformer or other suitable voltage regulator. The valve 32 was opened and the gas mixture flowed from the storage container (not shown) through the entrance tube 31 into the source housing and particularly into the arc chamber 14. The potential difference impressed between the filament 13 and the chamber walls 12 caused an arc discharge to appear and electron bombardment in the arc to effect ionization of the gaseous atoms. Now, when the magnet poles 35 of the cyclotron (between which the source is disposed

when properly placed in relation to the electrodes 36 and 37) were energized so that a magnetic field of about five thousand gauss existed, the electron beam was strongly collimated in a direction coaxial with the capillary and because the filament 13 is negative with respect to the housing 12, electron acceleration takes place. The gaseous atoms escaping through the capillary, by reason of the difference in pressure between the chamber 14 and the cyclotron electrodes are thus bombarded and ionized in the capillary by a high intensity accelerated electron beam. The ionized particles impinge upon the deflecting surface 25 where a remarkable amount of separation of undesired ions takes place. Upon energizing the electrodes with the alternating potential which acts as the accelerating electric field and properly tuning the frequency a sharply focused beam was produced at the target zone of the cyclotron. With such operating conditions prevailing, it was determined that about 5×10^5 tritium ions per second were obtained at the target zone in a beam having dimensions of one-eighth of an inch by one-half an inch. When the original dilution of tritium atoms is considered, the number of charged particles thus obtained indicates an extremely high efficiency in ion source operation and a relatively high degree of separation of undesired ions.

It has been found that upon the application of a surrounding magnetic field, parallel to the axis of the capillary, the energy of the accelerated particles can be varied to a great extent by variation in the intensity of the magnetic field and the frequency of the electric field and sharp focusing of the particle beam accomplished. Furthermore, the size of the capillary and the angle of the deflecting member were found to affect the charged particle separation previously mentioned.

The apparatus disclosed has been found fully operative for the purposes stated and while a preferred embodiment has been described for use in a cyclotron, variations will be apparent to anyone skilled in the art whereby the source may be adapted for use in other accelerating devices or the like. For example, in the preferred embodiment, the magnetic field which served to collimate the electron and emergent ion beams as above described is supplied by the magnets which form part of the cyclotron structure. It is clear that in another type of apparatus for accelerating charged particles or for utilizing gaseous ions in other ways it may be necessary to supply a magnetic field independent of the accelerating structure as well as an electric field to effectively withdraw the ions from the source. Similarly, other changes in the shape and combination of the various parts will suggest themselves to one skilled in the art based upon the teachings of this invention. Consequently, no limitation should be placed upon the scope hereof by reason of the description of a preferred embodiment or the mode of operation set forth except such limitations as are expressed in the subjoined claims in which it is the intention to claim all novelty in view of the prior art.

What is claimed is:

1. Apparatus for the production of ions comprising a frusto-conical chamber, a capillary passage positioned axially of the frusto-cone and providing an opening into the chamber, a metal deflecting member having a plane surface supported outwardly of the capillary passage and at an acute angle to the axis thereof, an electron source filamentary electrode supported in the base of the frusto-conical chamber, means for impressing an ionizing potential between the filament and frusto-conical chamber walls and means for introducing a selected gas in said chamber.

2. An ion source for a cyclotron and the like comprising a hermetic housing including a frustum chamber, a wall closing the small end of the frustum chamber and being provided with an elongated capillary passage having its axis aligned with the axis of the frustum chamber, a filamentary electrode supported in the plane of the large end of the frustum along a median line thereof and intersecting the axis thereof, means for injecting a selected gas into said chamber, means for impressing a negative potential gradient from the filament to the chamber walls, and a conducting member supported on the small end of the frusto-cone and having a planar surface making an acute angle with the axis of the capillary passage.

3. An improved ion source apparatus for cyclotrons and the like comprising a first base portion, a hollow stem portion and an ion generating frustum, said base portion comprising a cylindrical housing and means for supporting a first end of the stem portion axially thereof, said ion generating frustum being supported on a cylindrical base portion, and the second end of the stem portion being affixed diametrically to the cylindrical base portion, a filamentary electrode insulantly supported in the cylindrical portion and provided with electrical conductors, the electrical conductors being supported in the stem portion and leading out through the first base portion, means for impressing a potential on the frustum positive with respect to the filament, a capillary passage extending through the frustum small end with the axis thereof aligned with the axis of the frustum, a deflecting planar surface supported on the small end of the frustum with the plane thereof defining an acute angle with the capillary passage axis and means for introducing a selected gaseous medium into the apparatus supported on the first base portion.

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