

March 28, 1961

S. KLEIN
ION SOURCE

2,977,495

Filed June 3, 1959

3 Sheets-Sheet 1

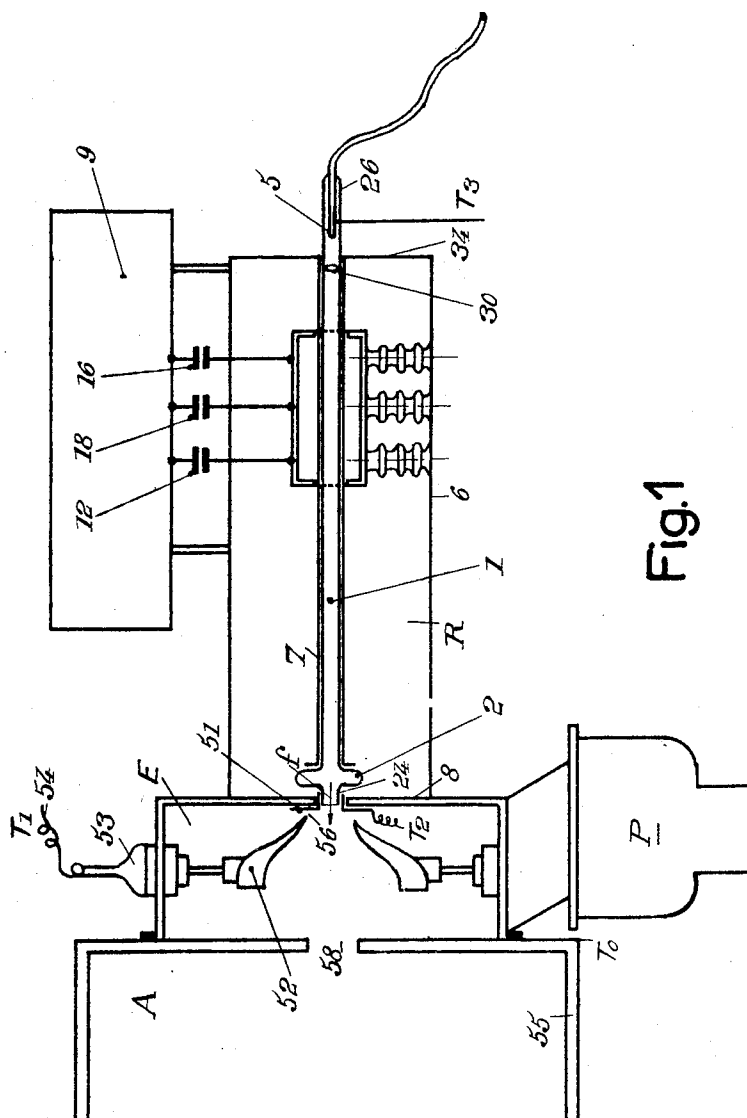


Fig. 1

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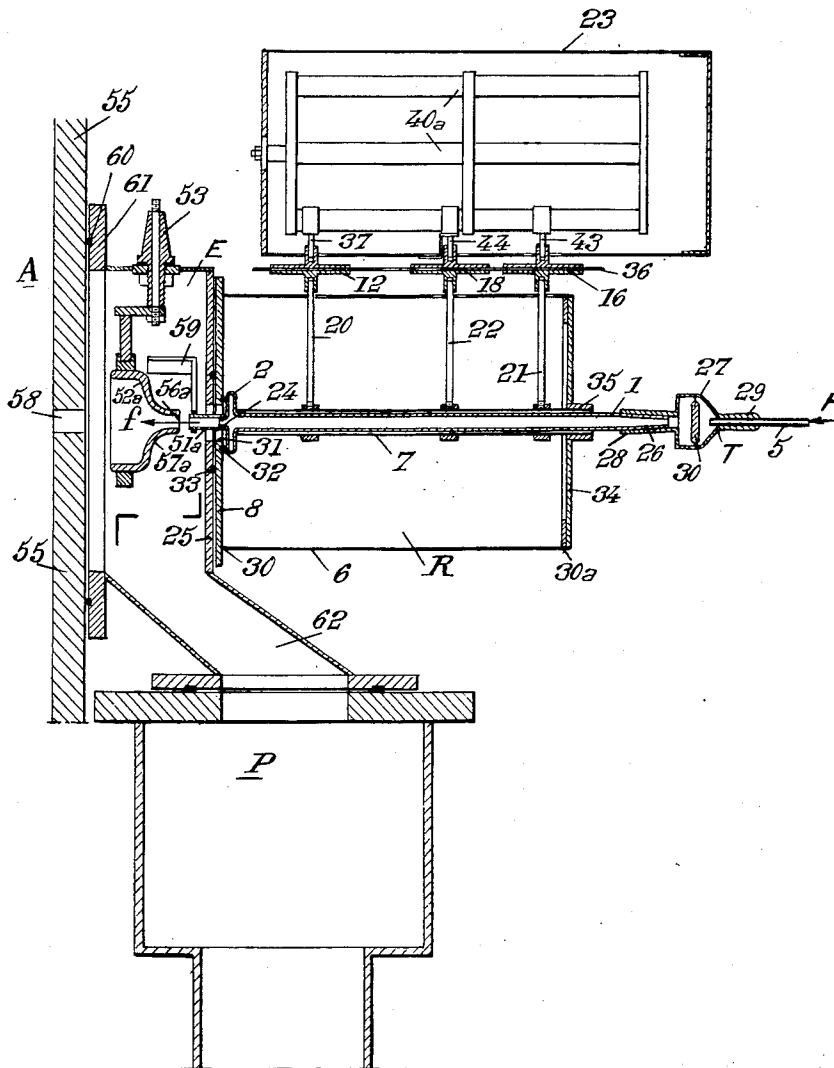
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Fig. 2.



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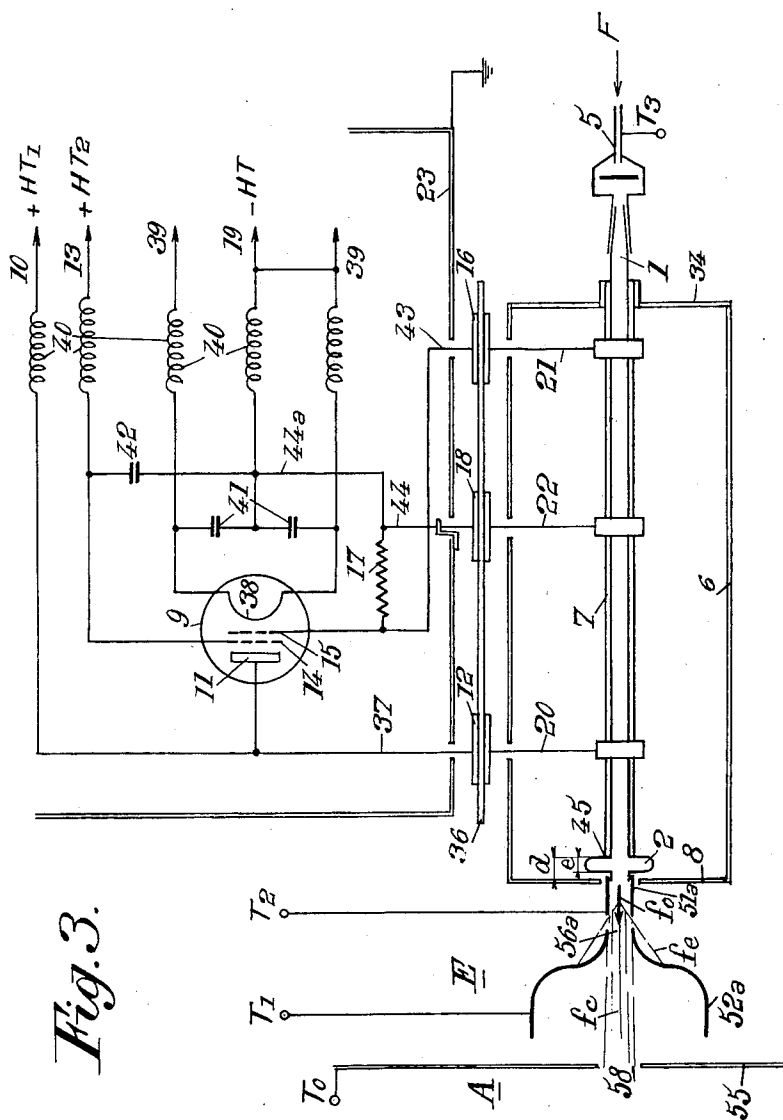
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ION SOURCE

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9 Claims. (Cl. 313-63)

The present invention relates to ion sources, that is to say to devices for producing beams of ionized particles for use in various apparatus for the treatment of such particles, such as particle accelerators, mass spectrometers, isotopic separation systems. The invention is more especially concerned with ion sources in which ionization of the particles is obtained by applying a high frequency electric field to an insulating chamber generally made of quartz or glass (in particular of the type constituted by a mixture of aluminium and sodium borosilicate sold under the trademark "Pyrex").

The invention consists chiefly, in an ion source including an evacuated ionization chamber, means for feeding said chamber with a stream of the gaseous product to be ionized and an extraction electrode, located in an evacuated enclosure adjoining said chamber, for extracting the ions formed in said chamber to the outside thereof, in disposing said extraction electrode in the vicinity of said chamber but on the outside thereof.

Advantageously there is provided, downstream of said extraction electrode, an accelerating and collecting electrode having a central orifice located, with respect to the extraction electrode, in such manner as to collect only the central portion of the ion beam extracted from said chamber by said extraction electrode.

Furthermore, the above mentioned feed means preferably include a feed electrode and means for applying decreasing high potentials to said feed electrode, extraction electrode and accelerating and collecting electrode, respectively.

The invention is intended to be more particularly applied to an ion source including an insulating tube, means for producing a high vacuum in said tube, means for applying a high direction potential difference between the two ends of said tube, means for feeding one of the ends of said tube with a product to be ionized, said product being in gaseous form, a source of high frequency current and a resonating cavity energized by said source and including a restricted zone of very intensive high frequency field, said tube including, in the vicinity of its other end, an enlarged portion forming a flat bulb disposed in said restricted zone, ionization being achieved in this enlarged portion.

The ion source according to the invention is more especially but not exclusively intended for the ionization of gases (such as hydrogen, deuterium, helium and nitrogen) or vapors (for instance of light metals, such as lithium and sodium) so as to produce a beam of ionized particles intended to be fed to a particle accelerator, with a high ionic yield (averaging ten milliamperes for a high frequency power of about 75 watts).

Preferred embodiments of the present invention will be hereinafter described with reference to the accompanying drawings, given merely by way of example and in which:

Fig. 1 is a diagrammatic view, in longitudinal sec-

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tion, of a first embodiment of an ion source according to the present invention.

Fig. 2 is a longitudinal sectional view of a second embodiment of said ion source.

Fig. 3 shows the electrical lay-out of the ion source of Fig. 2.

The ion source proper comprises a tube 1 of an insulating material, for instance of quartz or a glass such as that sold under the trademark "Pyrex," one end 26 of such tube being fed with the gas or vapor to be ionized through a hollow electrode 5 located in the vicinity of a quartz disc 30 (intended to increase the disruptive voltage of the gaseous medium inside tube 1), the other end 24 of the tube including an enlarged portion 2 in the form of a flat bulb of small dimension (of a volume of about one cubic centimeter for instance).

Tube 1 is partly housed in a coaxial resonating cavity R, for instance of copper, comprising an inner hollow conductor 7 partly surrounding said tube, an external conductor envelope 6 coaxial with conductor 7 and two metal plates 8 and 34 extending transversely to conductor 7, plate 8 being connected to envelope 6 and plate 34 being connected both to envelope 6 and to conductor 7.

This resonating cavity R is energized by an oscillator 9 which is coupled in a capacitive manner, through capacitors 12, 16 and 18, with internal conductor 7, as described in the co-pending patent application filed in this country in the present name on the last days of April 1959 or the beginning of May 1959, for "Improvements in Ion Sources," claiming priority of the French patent application Ser. No. 764,698 of May 3, 1958.

A high vacuum ranging from 10^{-3} to 10^{-4} mm. of mercury is maintained in tube 1 and also in the extraction space E which extends between this tube 1 and the particle accelerator A, this vacuum being obtained by means of a pump 13.

According to the present invention, there is provided in space E an extraction electrode 51 a portion of which is cylindrical and surrounds the end of tube 1, the other portion being located in a transverse plane. This extraction electrode 51 is contiguous to bulb 2 but it is located on the outside of tube 1. This electrode 51 is held at a high negative potential (averaging for instance 5000 volts) with respect to the hollow electrode 5 for the introduction of the gas or vapor to be ionized, in such manner as to form between these two electrodes 5 and 51 an electrostatic field which accelerates the positive ions toward the outside of tube 1, in the direction of the left hand side of Fig. 1.

The ions, produced essentially in bulb 2, located at the place where the high frequency field is maximum in resonating cavity R, and which are extracted from tube 1 and accelerated by extraction electrode 51 so as to form a beam indicated by arrow f, are caught by an accelerating electrode 52 carried by an insulating support 53 and brought by a conductor 54 to a potential intermediate between that of electrode 51 and that of the casing 55 of the particle accelerator A, which can be grounded (potentials T_3 , T_2 , T_1 and T_0 having respective values decreasing from T_3 to T_0 inclusive). This electrode 52 causes the ions to flow through the central aperture 56 thereof directly toward the opening 58 of the particle accelerator A.

Another embodiment of an ion source according to the present invention is shown by Figs. 2 and 3.

In this embodiment, the ion source proper (Fig. 2) essentially includes a tube 1, generally made of "Pyrex" glass or quartz, one end 24 of which is provided with an enlarged portion 2 in the form of a flat bulb of small dimension, for instance of a volume averaging one cubic centimeter.

The other end 26 of tube 1, of conical shape, carries the device T for the feed of the gas or vapor to be ionized. This device includes a chamber 27 with two hollow extensions 28 and 29, extension 28 fitting on the end 26 of tube 1 and extension 29 holding a hollow electrode 5 through which is introduced, in the direction of arrow F, the gas or vapor to be ionized. Chamber 27 contains a quartz disc 30 intended to increase the disruptive voltage of the gaseous medium inside the ion source.

Over most of its length, tube 1 is housed in a coaxial resonating cavity R which comprises the following elements:

A central hollow conductor 7 closely surrounding said tube;

A conductor envelope 6 coaxial with said central conductor 7 and located at a distance therefrom;

A metal plate 8, welded at 30 to the external envelope 6 so as to be electrically connected therewith, this plate closing one end of envelope 6 and being provided with a central hole 31 for the passage of the ions produced in bulb 2 and leaving tube 1 in the direction of arrow f;

A metal plate 34 located at the other end of envelope 6 and welded at 30a thereto, said plate 34 being rigid with a sleeve 35 fixed on conductor 7;

Toroidal rubber joints 32 and 33 inserted between plate 8 and bulb 2 on the one hand and between said plate 8 and the wall 25 of the extraction chamber E on the other hand.

Elements 6, 7, 8, 34 and 35 are good conductors of electricity and made for instance of copper.

In the extraction chamber E are disposed the extraction and acceleration cylindrical electrode 51a carried by an insulating support 59 so as to be contiguous to bulb 2 but located on the outside of tube 1, and the accelerating electrode 52a which is cup-shaped and carried by insulating support 53. This last mentioned electrode 52a collects, through its opening 56a, the central portion of the beam of ions extracted and accelerated by electrode 51a, the peripheral portion of this beam being stopped by the external wall 57a of electrode 52a so that only the central portion of beam f reaches the opening 58 of the particle accelerator A. A packing toroidal joint 60 is disposed between the wall 61 of chamber E and the wall 55 of the particle accelerator A.

Pumping means (shown at P) communicate with chamber E through conduit 62, so as to maintain a vacuum ranging from 10^{-3} to 10^{-4} mm. of mercury in tube 1.

Current is fed in the following manner (Fig. 3):

There is applied a high direct potential difference between electrode 5 (potential T_3) and the extraction electrode 51a (potential T_2) which is, in turn, kept at a high potential with respect to electrode 52a (potential T_1) and to the wall 55 of accelerator A (potential T_0); for instance, the following potentials may be applied:

	Volts
T_3 -----	+20,000
T_2 -----	+15,000
T_1 -----	+2,000
T_0 -----	+0

A high frequency voltage is applied to internal conductor 7 from an oscillator tube 9 (located in a shielding casing 23) by means of three copper rods 20, 21, 22 through three capacitors 12, 16 and 18 the conducting plates of which are separated from each other, respectively, by a single sheet of mica 36, about 0.1 mm. thick, in such manner as to achieve a capacitive coupling between the resonating cavity and the oscillator, which makes it possible to keep them at very different potentials respectively. For instance, the casing 23 of the high frequency source is grounded.

The oscillator tube 9 is for instance a tetrode calculated to consume about 75-100 watts at a frequency averaging 150 MHz., this tube being fed with a plate high voltage +HT₁ applied to plate 11 through line

10, with a screen high voltage +HT₂ applied to screen-grid 14 through line 13 and with a heating voltage applied to cathode 38 through wires 39, current return taking place through the common line 19 which constitutes the negative terminal -HT of the feed high voltages. Choke coils 40, wound on rods 40a (Fig. 2) prevent return flow of the high frequency currents produced by tube 9, and capacitors 41, 42 prevent the flow of direct current directly toward line 19. The control grid 15 of tube 9 is connected on the one hand directly to conductor 43 leading to capacitor 16 and on the other hand, through a resistance 17 of some thousands of ohms, to conductor 44 leading to capacitor 18 which is connected, through conductor 44a, to the return line 19, that is to say to the cathode from the high frequency view point. Finally, the plate voltage is applied, through conductor 37, to capacitor 12. Thus, tube 9 cooperates with resonating cavity R to form an oscillating system having a high Q coefficient.

The numerical values of the elements illustrated by Fig. 3 may be as follows:

+HT ₁ -----	volts--	+700
+HT ₂ -----	do-----	+1500
-HT-----	do-----	0
41-----	pf--	1500
42-----	pf--	6800
Frequency-----	MHz--	150
17-----	ohms--	20,000

The resonating cavity is thus energized through conductors 20, 21, 22 so as to produce a concentrated high frequency field between the end 45 of conductor 7 and plate 8, which are located at a distance d from each other hardly greater than the thickness e of the bulb. These two last mentioned elements act as a capacitor, whereas the inside of the envelope of the resonating cavity constitutes the self-inductance of the corresponding oscillating circuit, as explained in the above mentioned patent application with reference to Figs. 3 and 4 thereof.

The concentration of the lines of force of the electric field in a restricted zone of the resonating cavity, where is located the ionization zone (bulb 2 of tube 1) ensures a high ionization of the gas or vapor placed in said bulb 2. Furthermore, due to the fact that the Q factor of a resonating cavity may be very high for very high frequencies (in opposition to what takes place in lumped constant resonating circuits), it is possible to start the ionization of the gas or vapor in bulb 2 very easily, because the field is very intensive in this bulb before ionization. It is thus possible to obtain a cavity of the type shown by the drawings having a Q factor averaging 1000 which ensures a very easy starting of ionization.

Another very important advantage of the arrangement according to the invention lies in the fact that the ionization zone (bulb 2) is contiguous to the extraction zone, extraction taking place through electrode 51 or 51a located on the outside of tube 1. Furthermore, extraction chamber E is of small length because it comprises only electrodes 51 and 52 (or 51a and 52a) to lead the ions to the device for which they are intended, such as a particle accelerator.

Finally, the operation of the ion source above described is as follows:

The gas or vapor to be ionized arrives through electrode 5 and it is essentially ionized in bulb 2 located in a maximum high frequency zone. Ionization takes place in this bulb with a high intensity, which permits of obtaining a beam f of high intensity containing a relatively high proportion of ions. The ions thus obtained are then subjected, by extraction and acceleration electrode 51a and accelerating and collecting electrode 52a, to an accelerating field which drives them toward the particle accelerator A. The ions which would already have a tendency to diverge (peripheral zone of beam f) are stopped by the external walls 57a of the accelerating and

collecting electrode 52a, as shown for the ion rays f_c on Fig. 3, whereas the central portion f_o of beam f_o is led toward orifice 58. The accelerating and collecting electrode collects from 50 to 80%, and preferably about 75%, of the initial beam f_o .

The location of electrodes 51, 52, or 51a, 52a, in the extraction chamber E according to the above described embodiments, has many advantages:

Electrode 51, 51a is protected against an ion bombardment which would destroy it more or less rapidly as it is the case in ion sources having an extraction electrode housed in the insulating tube of the source;

It prevents the ions that are to be used from reaching metal surfaces which would facilitate their recombination;

It permits of applying, without risks of injury, sufficiently high differences of potential between electrode 5 and electrode 51, 51a, so that said electrode 51, 51a also acts as an accelerating electrode, which makes it possible to dispense with at least one of the electrodes normally used for this purpose in the known devices including an ion source and an accelerator;

It reduces the path of travel of the ions between the ionization chamber constituted by bulb 2 and the inlet 58 of the particle accelerator, thus reducing the number of shocks between the ions and the gas molecules present in this interval.

These advantages permit of producing an ion source which has:

A high ionic yield, on the one hand because the path of travel of the ions is reduced and on the other hand because, in the case of the second embodiment above described, electrode 52a collects only ions having little tendency to diverge and does not include metal surfaces which might facilitate recombination of the ions that are collected;

Small angles of aperture (ranging from 2 to 3°) for the ion beam which is thus well focussed.

Finally, such a source permits of producing in very good conditions atomic hydrogen ions (protons) due to the fact that no metal surface which might produce a secondary emission of electrons capable of neutralizing the protons by combination therewith is present across the path of travel of the ions that are produced. The ion beams that are obtained contain at least 70% of protons among the hydrogen ions.

Instead of giving potentials T_2 , T_1 and T_0 respective values which decrease from one to the other, potential T_1 might be made lower than potential T_0 , so as to obtain an electrostatic focussing of the ion beam which would complete the mechanical focussing resulting from the particular shape of electrode 52a.

In a general manner, while I have, in the above description, disclosed what I deem to be practical and efficient embodiments of my invention, it should be well understood that I do not wish to be limited thereto as there might be changes made in the arrangement, disposition and form of the parts without departing from the principle of the present invention as comprehended within the scope of the accompanying claims.

What I claim is:

1. An ion source which comprises, in combination, an evacuated ionization chamber, means for feeding said chamber with a stream of a gaseous product to be ionized, an evacuated enclosure adjoining said chamber and an extraction electrode in said enclosure for extracting from said chamber the ions formed therein, said extraction electrode being located close to said chamber but on the outside thereof.

2. An ion source which comprises, in combination, an evacuated tube of an insulating material, an ionization chamber close to one end of said tube and in communication therewith, a hollow electrode opening into the other end of said tube, said hollow electrode serving to the feed into said tube of a stream of a gaseous product to be ionized, an evacuated enclosure adjoining said chamber, an

extraction electrode in said enclosure for extracting from said chamber the ions formed therein, said extraction electrode being located close to said chamber but on the outside thereof, and means for applying a difference of potential of several thousands of volts between said feed electrode and said extraction electrode, said extraction electrode being at a lower potential than said feed electrode.

3. An ion source which comprises, in combination, an evacuated tube of an insulating material, a portion of said tube close to one end thereof forming an ionization chamber, said tube including a cylindrical extension beyond said ionization chamber, said extension being of a very short length, a hollow electrode opening into the other end of said tube, said hollow electrode serving to the feed into said tube of a stream of a gaseous product to be ionized, an evacuated enclosure adjoining said chamber and containing said cylindrical extension, an extraction electrode located in said enclosure for extracting from said chamber the ions formed therein, said extraction electrode being in the form of a cylindrical sleeve closely surrounding said extension of said tube, and means for applying a difference of potential of several thousands of volts between said feed electrode and said extraction electrode, said extraction electrode being at a lower potential than said feed electrode.

4. An ion source which comprises, in combination, an evacuated tube of an insulating material, an ionization chamber close to one end of said tube and in communication therewith, a hollow electrode opening into the other end of said tube, said hollow electrode serving to the feed into said tube of a stream of gaseous product to be ionized, an evacuated enclosure adjoining said chamber, an extraction electrode in said enclosure for extracting from said chamber the ions formed therein, said extraction electrode being located close to said chamber but on the outside thereof, means for applying a difference of potential of several thousands of volts between said feed electrode and said extraction electrode, said extraction electrode being at a lower potential than said feed electrode, an accelerating electrode located in said enclosure downstream of said extraction electrode, and means for applying a difference of potential of several thousands of volts between said extraction electrode and said accelerating electrode, said accelerating electrode being at a lower potential than said extraction electrode.

5. An ion source which comprises, in combination, an evacuated tube of an insulating material, a portion of said tube close to one end thereof forming an ionization chamber, said tube including a cylindrical extension beyond said ionization chamber, said extension being of a very short length, a hollow electrode opening into the other end of said tube, said hollow electrode serving to the feed into said tube of a stream of a gaseous product to be ionized, an evacuated enclosure adjoining said chamber and containing said cylindrical extension, an extraction electrode located in said enclosure for extracting from said chamber the ions formed therein, said extraction electrode being in the form of a cylindrical sleeve closely surrounding said extension of said tube, means for applying a difference of potential of several thousands of volts between said feed electrode and said extraction electrode, said extraction electrode being at a lower potential than said feed electrode, an accelerating electrode located in said enclosure downstream of said extraction electrode, and means for applying a difference of potential of several thousands of volts between said extraction electrode and said accelerating electrode, said accelerating electrode being at a lower potential than said extraction electrode.

6. An ion source according to claim 4 in which said accelerating electrode is a collecting electrode including a central orifice opposite said first mentioned end of said tube and divergent walls starting from said orifice in the downstream direction, said collecting and accelerating electrode being located downstream of said extraction

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electrode so that the central orifice of said collecting electrode collects only the central portion of the ion beam extracted from said ionization chamber by said extraction electrode.

7. An ion source according to claim 5 in which said accelerating electrode is a collecting electrode including a central orifice opposite said first mentioned end of said tube and divergent walls starting from said orifice in the downstream direction, said collecting and accelerating electrode being located downstream of said extraction electrode so that the central orifice of said collecting electrode collects only the central portion of the ion beam extracted from said ionization chamber by said extraction electrode.

8. An ion source according to claim 1 in which said ionization chamber is constituted by a flat bulb, said ion source including a high frequency current source and a resonating cavity at least a portion of which surrounds said bulb, said cavity being coupled with said current source to be energized by it and being arranged to form a zone of concentrated electric field including, and substantially limited to, the volume occupied by said bulb.

9. An ion source according to claim 3 in which said ionization chamber is in the form of a flat bulb extending transversely to the direction of said tube, said ion source including a high frequency current source and a resonating cavity at least a portion of which surrounds

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said bulb, said cavity being coupled with said current source to be energized by it and being arranged to form a zone of concentrated electric field including, and substantially limited to, the volume occupied by said bulb, said resonating cavity being constituted by a hollow central conductor closely surrounding said tube from said second mentioned end thereof to said bulb, a conductor casing surrounding said central conductor coaxially thereto and at a distance therefrom, a transverse conductor plate rigid and in electric contact with said central conductor at a point thereof remote from said bulb and located on the same side thereof as said second mentioned end of said tube, said plate being in electric contact with one end of said envelope, and a transverse conductor plate rigid and in electric contact with the other end of said envelope extending on the other side of said bulb from said first mentioned plate at a distance from said bulb just a little greater than the thickness thereof.

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