United States Patent
Wahlin

[15] **3,649,862**

[45] **Mar. 14, 1972**

[54] **SEPARATED ION BEAM SOURCE WITH ADJUSTABLE SEPARATION**

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[22] Filed: **May 1, 1969**

[21] Appl. No.: **821,021**

[52] **U.S. Cl.** ....**313/63**, 250/41.9 SB, 250/41.9 ME, 313/230

[51] **Int. Cl.** **H05h 5/00**

[58] **Field of Search** ....313/63, 230; 250/41.9, 41.92, 250/41.95, 41.9 SB, 41.9 ME, 41.9 TF; 315/111

[56] **References Cited**

UNITED STATES PATENTS

2,507,652 5/1950 Smith....................................313/63 X

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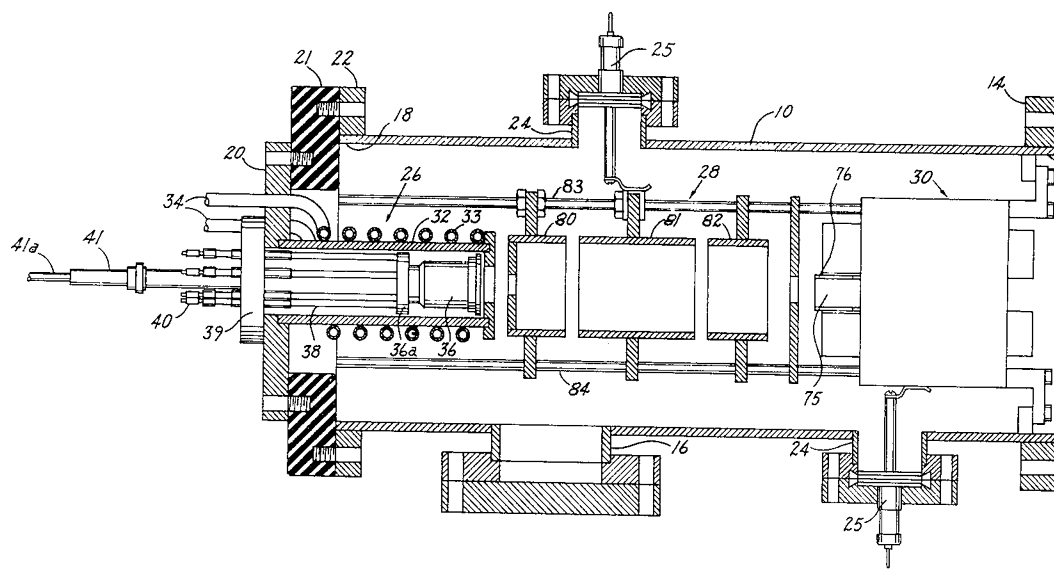
[57] **ABSTRACT**

An ion beam source includes an ion source, ion accelerator and focusing system, and a velocity filter with a deflection plate pair. The velocity filter provides for dispersion of ions according to their charge, mass and velocity. The ion source includes a nonconducting barrel, a filament mounted in the barrel and an anode enclosing the barrel opening except for a source aperture. Filament current is arranged to provide an electron current to the anode, this electron current ionizes the charge material thus forming a plasma cloud for ejecting into the focusing and lens system, and then into a velocity filter causing separation of ion beam.

15 Claims, 14 Drawing Figures



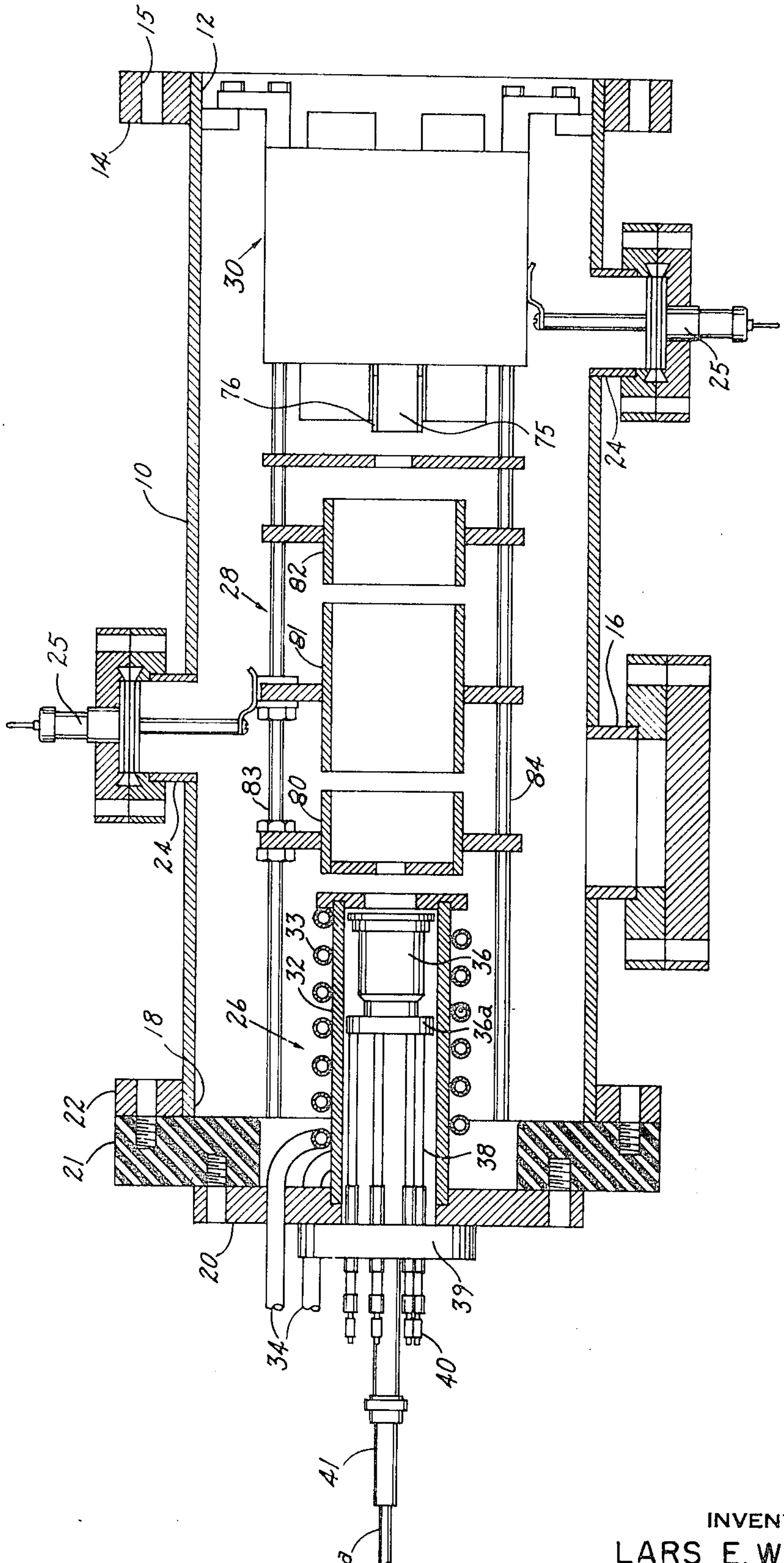


Fig. 1

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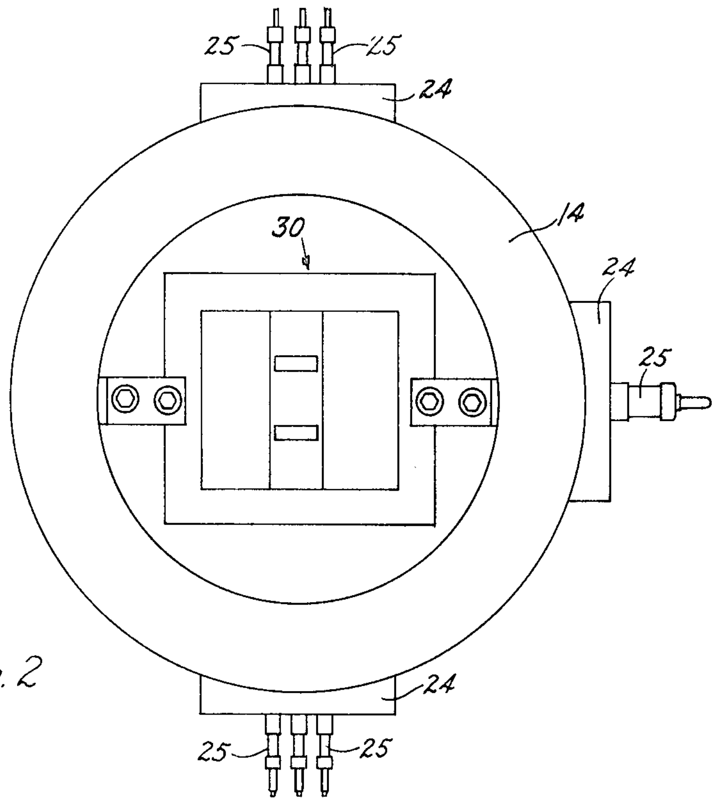

Fig. 2

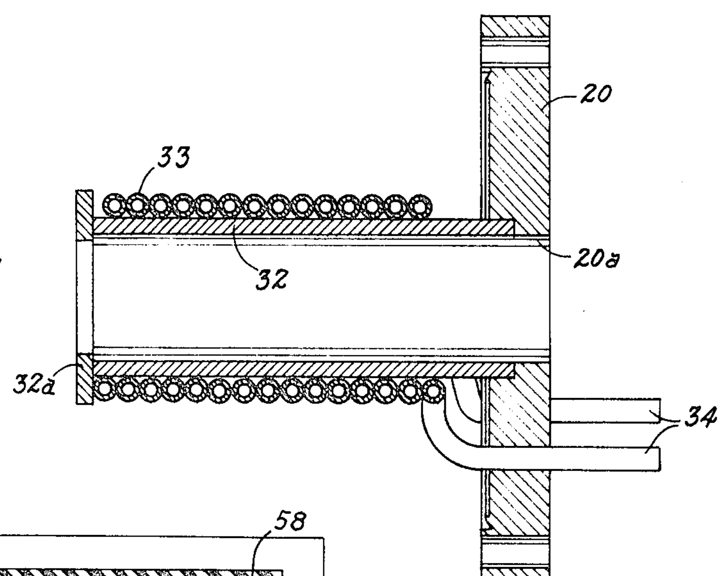

Fig. 4

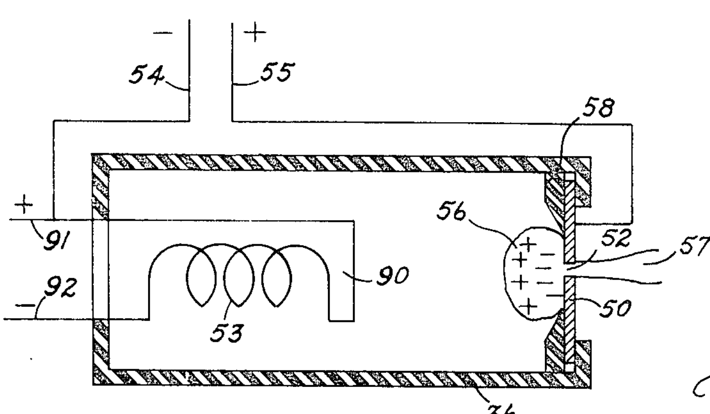

Fig. 3

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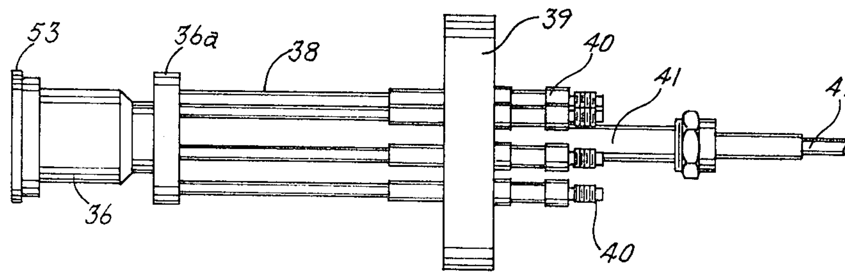

Fig. 5

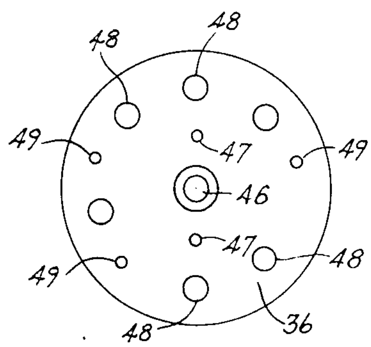

Fig. 7

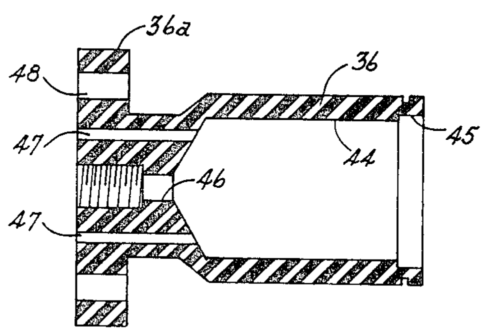

Fig. 6

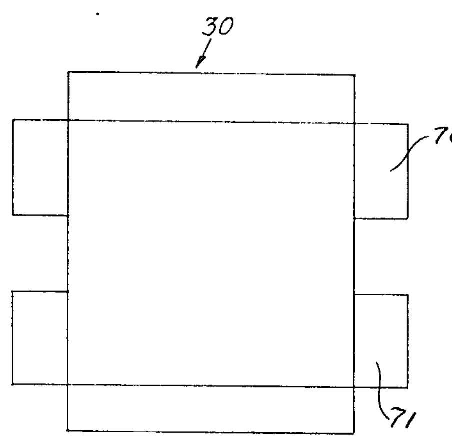

Fig. 8

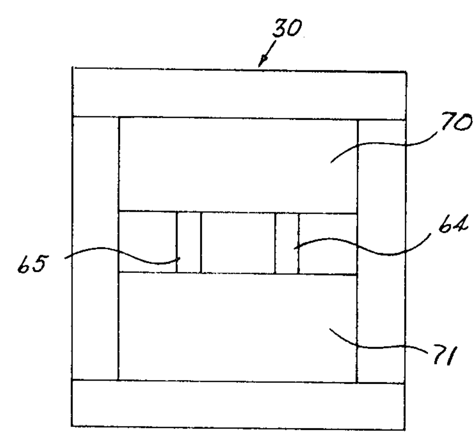

Fig. 9

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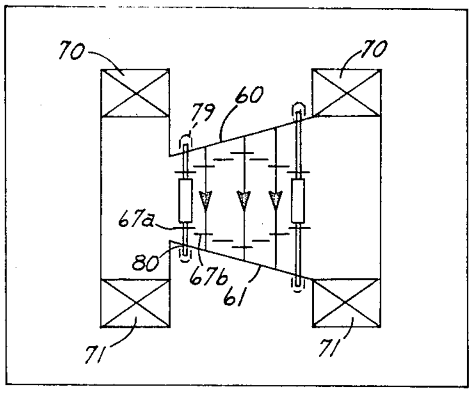

Fig. 10

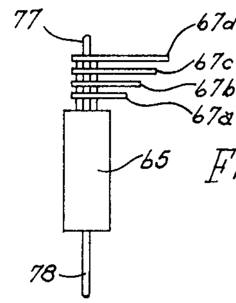

Fig. 13

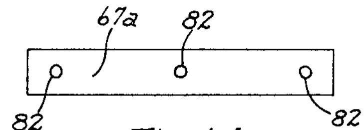

Fig. 14

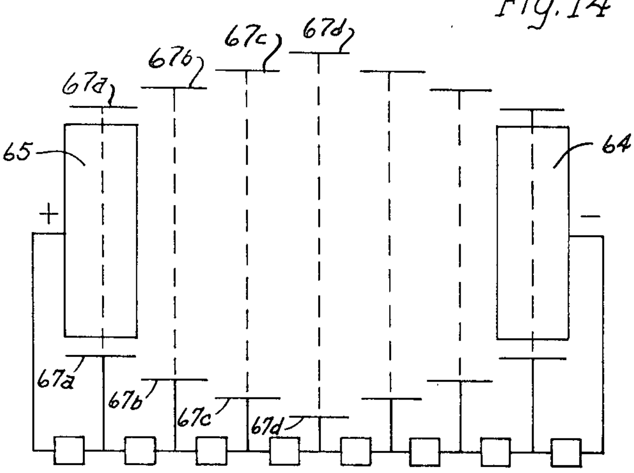

Fig. 11

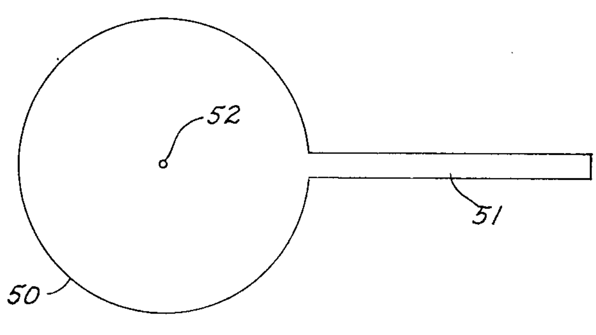

Fig. 12

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SEPARATED ION BEAM SOURCE WITH ADJUSTABLE SEPARATION

Prior ion beam sources of mass separated ion beams used sifter magnets as analyzers for the ion beam. Such units are massive, extremely heavy machines requiring installation on special foundations and therefore are of limited use. Further, the ion source utilized a metal body as the anode, and a heavy electric coil for producing the magnetic field in the production of an ion beam. One disadvantage incurred in previous ion separators is that contamination of the ion source parts required a complete overhaul of the ion source with the result high expense and considerable downtime for the unit.

According to the present invention we have provided a low intensity separated ion beam source having a velocity filter which may be utilized for separated beams for use in accelerators, e.g., cyclotrons, separation of radioactive isotopes; spectrometers, e.g., beta spectrometers; ion beam injectors for accelerators. The small size of the present unit is a reduction of about 50 times the size and weight of prior separators producing a similar beam providing substantial cost reduction. The ion source has a nonconductive ceramic body, an inner filament and a disc anode with a small aperture producing a uniform beam having greatly increased efficiency and without the necessity of a magnetic field surrounding the ion source. The ion source is readily removed from the unit, and replaced with minimum cost in the event of contamination. The disc anode of the ion source constricts the plasma cloud around the opening increasing the efficiency of the beam production, and preventing a buildup of the plasma cloud on the nonconductive ceramic body. The velocity filter reduces the overall size and massiveness of the separator and provides for an adjustable dispersion of ions. All ions are accelerated at the same voltage, but their velocities are inversely proportional to the square root of their masses.

Included among the objects and advantages of the present invention is a separator for ion beams providing a highly efficient ion source and a velocity filter for dispersion of ions in an ion beam according to their masses.

Another object of the invention is to provide an ion source utilizing a nonconductive body and a disc anode for concentrating a plasma cloud at the opening of the ion source.

A further object of the invention is to provide a velocity filter having tapered plates on the magnetic elements to compensate for the focusing effect on an ion beam passing therethrough.

A further object of the invention is to provide a modular construction for an ion separator including readily removable elements such as an ion source, a lens focusing system and a velocity filter.

Yet another object of the invention is to provide a fully enclosed ion beam source for mass separated beams.

Another object of the invention is to provide an adjustable mass separation for an ion beam.

These and other objects and advantages of the invention may be readily ascertained by referring to the following description and appended illustrations in which:

FIG. 1 is a side elevational view, in cross section, of an ion beam separator assembly according to the invention;

FIG. 2 is an end elevation of the device of FIG. 1 taken at the velocity filter end;

FIG. 3 is a schematic view of an ion source according to the invention;

FIG. 4 is a generally schematic cross-sectional side elevational view of a ion source receptacle and heat sink for the ion beam separator of the invention;

FIG. 5 is a side elevational view of an ion source showing the modular construction of the unit;

FIG. 6 is a cross-sectional view of a barrel for an ion source according to the invention;

FIG. 7 is an end elevational view of the barrel of the ion source of FIG. 6;

FIG. 8 is a schematic side elevational view of a velocity filter according to the invention;

FIG. 9 is an end elevational view of the filter of FIG. 8;

FIG. 10 is a schematic end elevational view, diagrammatically illustrating, in a distorted sense, the configuration of the plates of the magnets of the velocity filter for compensating focusing effect;

FIG. 11 is a diagrammatic circuit for the plates of a velocity filter, illustrating the biased guard ring shims for compensating for the focusing effect of the lens system of a separator;

FIG. 12 is a plan view of an anode of an ion source;

FIG. 13 is an end elevation of a modified shim holding system; and

FIG. 14 is a plan view of a modified shim for the modified shim holding system.

The ion beam source illustrated in FIG. 1 includes a tubular barrel or housing **10** having an open end **12**, which has a flange **14** with bolt holes **15** for attachment to an accelerator or other beam using system for a separated ion beam. A side outlet **16** provides means for evacuating the housing. The opposite end **18** of the tube **10** is closed by an ion source support **20** bolted to an insulator flange **21** which in turn is bolted to a flange **22** mounted on the housing. Upper, lower and side outlets **24** hermatically sealed on the housing provide means for electrical connections **25** for a focus system, and velocity filter, explained below.

Mounted internally of the tube is an ion source, shown in general by numeral **26**, a focusing system shown in general by numeral **28** and a velocity filter shown in general by numeral **30**.

The ion source assembly, FIGS. **4**, **5**, **6** and **7**, includes a tubular receptacle **32** surrounded by the coils **33** of a heat sink having inlet and outlet connections **34** for cooling water, providing means for cooling the receptacle and contained ion source. The ion source includes a nonconducting barrel **36** having a flange **36*a***. Rods **38** are mounted in openings **48** and extend to a backing plate **39**. A tube **41** is secured to the barrel and communicates with orifice **46**. Electrical connections **40** extending through openings **47** of the barrel provide means for heating a filament of the source and charging the anode plate of the source. The probe tube **41** provides means for introducing a sample of the charge of gaseous material to be ionized, or in solid form, by sample holding probe rod **41*a*** into the filament of the ion source. The plate **39** is hermetically sealed by means of removable bolts to the plate **20** providing a unitized ion source which is readily removed from the housing along with the receptacle **32**.

The ion source includes the nonconducting barrel **36** providing a cuplike receptacle **44** having a rabbeted opening **45**. The central opening **46** provides means for inserting the probe **41*a*** into the cup, and the pair of electrode openings **47** provide means for insertion of the leads to a filament for heating a sample for producing a plasma cloud. Bolt holes **48** around the periphery of the flange **36*a*** of the ion source barrel permits attachment by means of the rods **38** to the flange plate **39**. Additional holes **49** provide means for insertion of additional electrical connections into the area around the barrel **36**. The barrel **36** is a nonconductive ceramic material, in one instance a boron nitride, but may be other nonconductive type materials. The source is easily assembled and disassembled.

An anode plate **50**, FIG. **12**, having an extending arm **51** is provided with a central aperture **52**, which is arranged to be placed over the opening in the barrel **36** mounted in the rabbit **45**. The arm **51** extends beyond the barrel and provides means for an electrical connection for the plate for inducing a charge on the anode plate. The plate may be made of tantalum metal, which is generally corrosion resistant and conducts an electrical current. A cap **53** secures the tantalum anode plate in position on the barrel **36**. A ceramic, nonconducting ring **58** in the barrel, abutting the anode, reduces the area of exposed anode metal in the barrel and concentrates a plasma cloud at the opening **52**.

The connections through the plate **39** are all hermetic seals so that electrodes and other members passing through the plate are sealed against air leakage as the unit operates under a very high vacuum. All seals must be airtight.

The heat sink for the ion source is shown in FIG. 4, where a tube 32 with a flanged end 32*a* is secured to the plate 20 having a central aperture 20*a* coinciding with the barrel 32. The cooling coils 33 for the heat sink are provided with inlet and outlet connections 34. The whole unit is then hermetically sealed to the insulating plate 21 permitting a ready attachment of the ion source into the tube 32, removably secured as by bolts and the like. Thus, the ion source is a modular unit which is easily attached or removed from the unit. As is noted above, all the electrical connections for the ion source pass through the plate 39 providing a self-contained unit. The tube 41 provides means for a probe 41*a* to pass therethrough into the filament in the barrel 36 for ionizing a solid material which may be contained on the end of the rod. Gas for ionization may, also, be passed through the tube 41, with requisite connections for introducing gas thereto attached to the rod, the same being not shown as it is a conventional arrangement. In each case the tube 41 extends into the opening 46 and permits the probe rod 412 to enter into the filament where a sample carried by the rod is heated and vaporized or gas is introduced into the filament. The heat sink is shown as a coil, but obviously may be a jacketed tube, or the like, which is conventional.

As illustrated in FIG. 3 the ion source barrel 36 is provided with a filament 90 internally thereof provided with leads 91 and 92 for inducing an electrical current on a coil 53. The filament provides the emission current for the anode circuit in which leads 54 and 55 provide the current for charging the cathode 90 and the anode plate 50. The lead 54 is tied into the circuit of the filament 90. At high vacuum with the charge material induced in the hot filament, the sample is èvaporated and then ionized. A charge on the anode plate 50 produces a plasma cloud 56 by means of electron bombardment producing an ion beam 57 which is extracted through the aperture 52 in the anode plate 50 by an external electric field between anode plate 50 and lens 80. Since the barrel 36 and the ring 58 are nonconducting and cannot draw any arc current, the plasma cloud is constricted to the plate 50 around the opening 52 substantially increasing the efficiency of the unit since the cloud does not attach to the inner wall of the barrel 36 or any other electrically insulating part as in prior art sources using a metal barrel with a high magnetic field therearound.

The focus system includes a series of electric cylinders 80, 81 and 82 which are reciprocally mounted on bus bars 83 and 84. The focus system draws the beam from the ion source, accelerating and focusing it into the desired shape for passing through the velocity filter. These focus and acceleration lenses, are electrostatic lenses, which produce electrostatic fields, first withdrawing the ions from the source, and then focusing the diverging beam from the ion source into a predetermined pattern desired by the electric fields. Such focusing systems are conventional.

The velocity filter includes a pair of horizontal magnetic coils around a pair of electromagnetic poles and a pair of vertical electrostatic deflection plates mounted between the magnetic poles. The plates produce an electric field perpendicular to the magnetic field (crossed electric and magnetic fields). When a beam of ions passes through the filter with a given velocity the beam will be deflected by the electrostatic field in one direction and by the magnetic field in the other. The magnitudes of these opposing bending forces are directly related to the electric and magnetic field strength in the filter and to the velocity of the ions passing therethrough. When the two opposing bending forces are equal for a given ion velocity then all ions with this given velocity will pass undeflected through the filter. Ions having other velocities are deflected to either side of the undeflected ion beam and are dispersed and separated according to their velocities. Since the ions entering the velocity filter are monoenergetic, velocity separation provides mass separation.

As illustrated in FIGS. 8–11, 13 and 14, the velocity filter includes magnetic poles 60 and 61, which are tapered, one side of the gap between them is longer than the other to produce a nonfocusing through the filter. Coils 70 and 71 around the poles produce the magnetic field between the poles. Electrostatic deflection plates 64 and 65 provide horizontal electric field for the beam. As illustrated in FIG. 11, guard shims, mounted between the vertical plates, also, compensate for the focusing effect otherwise obtained. The shims 67*a*, 67*b* and 67*c* and 67*d* are mounted between the electrostatic deflection plates and each is charged by a circuit controlled by potentiometers therebetween and together with the deflection plates provide an adjustable field, and change the effect of the field on the beam. This provides an adjustable separation for the beam passing the velocity filter. Deflection plates 75 and 76, FIG. 1, are charged, electrostatically forming an electrostatic deflector for aligning the beam into the velocity filter. This is somewhat similar to the deflection plates of an oscilloscope. The shim pairs 67*a*, 67*b*, 67*c*, 67*d*, etc., prevent any focusing in the velocity filter, but permits the ions of the beam to be deflected providing high resolution of separation. The shims are mounted on pins 77 and 78 which extend into holes 79 and 80 in the poles 60 and 61, and in similar holes in the plates 64 and 65. The shims are insulated from each other and the pins. For a small size velocity filter (FIG. 14), a shim 67*a* has three bores 82 for mounting on three pins mounted in the plates. The shims are stacked one on the other. The shims, of course, run lengthwise of the filter, FIGS. 10 and 11 being end views. The shims are mounted in opposed pairs, providing a space therebetween for the beam.

The velocity filter is nonfocusing; i.e., it does not have cylindrical or spherical lens effect. The tapered plates and the shims prevent such a lens effect of conventional filters. The strong focal property of prior filters limits the length of drift path between filter and collector target. The drift path magnifies the mass or velocity dispersion at the collector target. The above-described tapered magnetic pole plates and electrostatic guard rings in the form of metal shims eliminate the intrinsic focusing effect of the filter. This makes it possible to use any length of drift distance behind the filter and thus considerably increases the separating power of the system. One important feature of the velocity filter, and all components, also, is that they are completely enclosed in the housing. No external coils, or magnets are needed. To obtain good resolution, an ion beam must be accelerated at relatively high voltage, however, the unit of this invention has a much lower energy spread than with known beam sources which have a high energy spread. This is due to the highly efficient ion source, which provides the low energy spread ion beam. The unit is capable of accelerations from 10 ev. to 2 Kev. or more. The smallness and efficiency of the unit makes it valuable for ion implants, ion beams for chemistry, post acceleration units, etc.

What is claimed is:

1. An ion beam source with an adjustable ion separator comprising a tubular housing arranged for a hermetic connection by one end to a device for utilizing an ion beam; an ion source releasably mounted in said housing inclusive of electric filament means, and means for introducing charge material into said filament; said ion source being releasably and hermetically sealed in said housing; support means mounted internally of said housing adjacent to and extending away from said ion source; a plurality of electrostatic lenses adjustably mounted on said support means and completely enclosed in said housing; electric circuit means extending through and hermetically sealed in the wall of said housing and in conductive connection with said lenses; a velocity filter inclusive of a pair of electrostatic plates and a pair of horizontal coils, providing crossed magnetic and electric fields, mounted in lateral alignment forming a beam path therethrough and completely enclosed in said housing and in alignment with said lenses; and a plurality electrostatic shims spacedly mounted in opposed pairs in said beam path in said filter for guiding an ion beam through said velocity filter without a focusing effect; and means hermetically sealed through said housing for supplying an electric current to said coils in said velocity filter and to said shims.

2. An ion beam source according to claim 1 wherein said ion source is independently removable from said housing.

3. An ion beam source according to claim 1 wherein said support means forms a bus bar for said lenses, and said electric circuit means is connected to said support means.

4. An ion beam source according to claim 1 being further characterized by at least a pair of electrostatic deflection plates mounted between said lenses and said filter for aligning said beam in said filter.

5. An ion beam source according to claim 1 wherein said ion source includes a nonconducting body, a heating coil internally thereof and an apertured anode plate adjacent said lenses, whereby a plasma cloud formed in said ion source is attached to said plate around said aperture adjacent said lenses.

6. An ion beam source according to claim 1 wherein said ion source is mounted in a heat sink mounted in said housing.

7. A velocity filter for separating an ion beam comprising a pair of spaced-apart horizontal coils and a pair of spaced-apart vertical electrostatic deflector plates mounted in lateral alignment providing a beam path therebetween; said horizontal coils being provided with poles having opposed faces providing a boundary for a beam passed through said filter, and the faces of said poles being sloped so that one side of said path is narrower than the other; a plurality of shims mounted in opposed pairs on opposite sides of the beam path through said filter; said shims being staggered outwardly from each side of said path to the center thereof and each being insulated from each other; means for electrically charging said coils and plates; and means for charging opposed pairs of said shims.

8. A velocity filter according to claim 7 wherein said shims are mounted on pins depending from said poles and are insulated from said poles.

9. A velocity filter according to claim 7 wherein said means for charging said opposed pairs of shims is adjustable for adjusting the charge on said shims.

10. A velocity filter according to claim 7 further characterized by at least a pair of electrostatic deflection plates mounted at the opening of said filter for aligning a beam entering said filter.

11. An ion source for emitting an ion or plasma cloud in a vacuum comprising a nonmetallic tubular body having an open end and a generally closed end; means for mounting said body in a heat sink to dissipate generated heat; an electric heating filament mounted in said body; there being an opening in said closed end arranged to permit a probe to be introduced into said filament; a conducting metal disc with a central aperture closing the open end of said body including electric connection means extending from said disc; and electric circuit means for heating said filament and charging said disc.

12. An ion source according to claim 11 wherein a nonconducting washer member is mounted at the opening of said body abutting said disc to reduce the exposed surface area of said disc internally of said body.

13. An ion source according to claim 12 wherein said body and said washer are made of a ceramic material.

14. An ion source according to claim 11 wherein said body is boron nitride.

15. An ion source according to claim 11 wherein said heating filament is arranged as the cathode for said anode plate, and provides an electric discharge on said plate for gathering and holding a plasma cloud produced by said discharge.

* * * * *