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J. G. BACKUS ET AL

2,658,150

METHOD AND APPARATUS FOR FOCUSING CHARGED PARTICLES

Filed Dec. 3, 1946

4 Sheets-Sheet 1

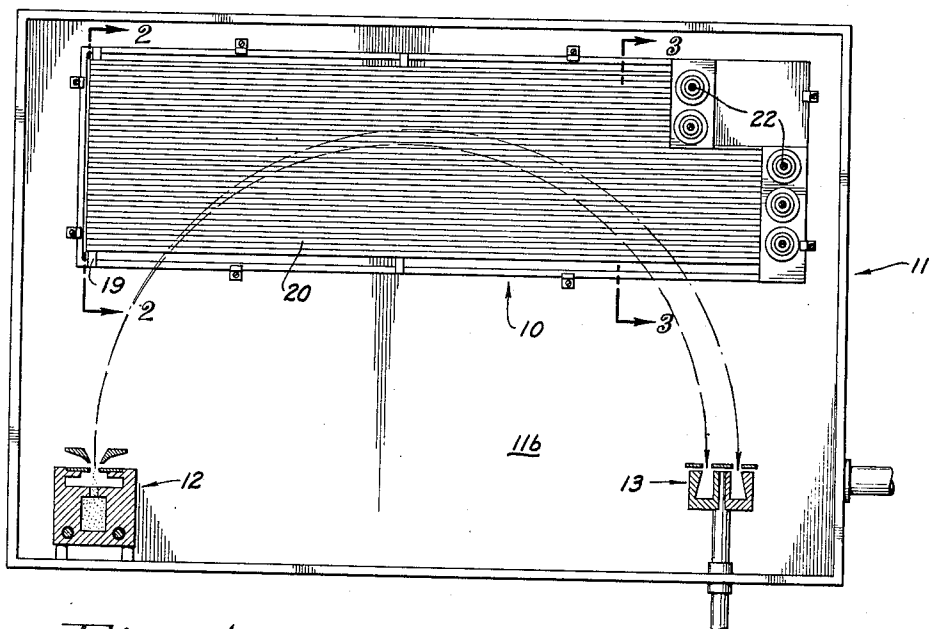


Fig. 1

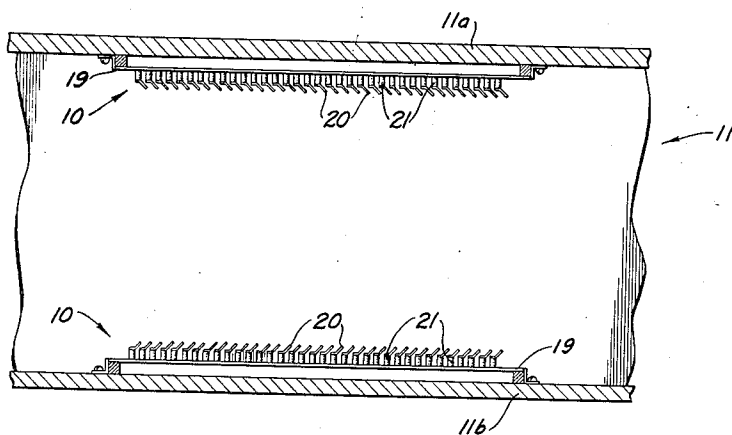


Fig. 2

INVENTORS.
JOHN G. BACKUS
BERNARD PETERS

BY

Roland A. Anderson
ATTORNEY

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4 Sheets-Sheet 2

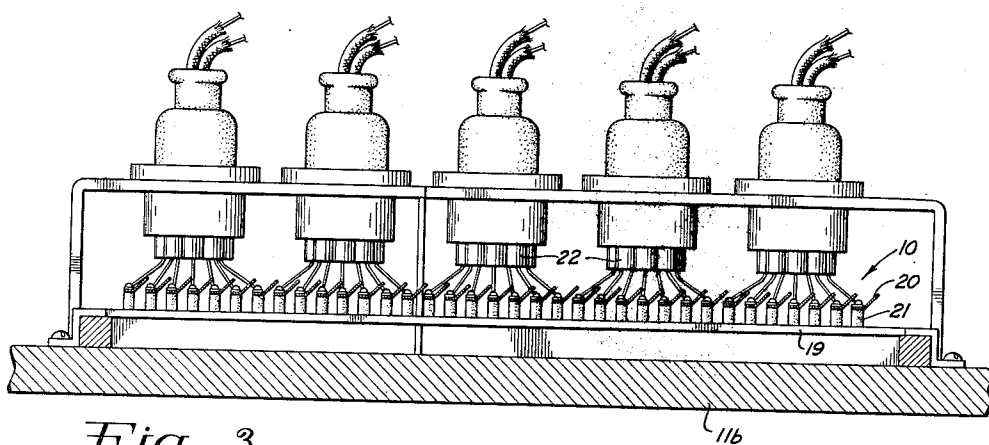


Fig 3

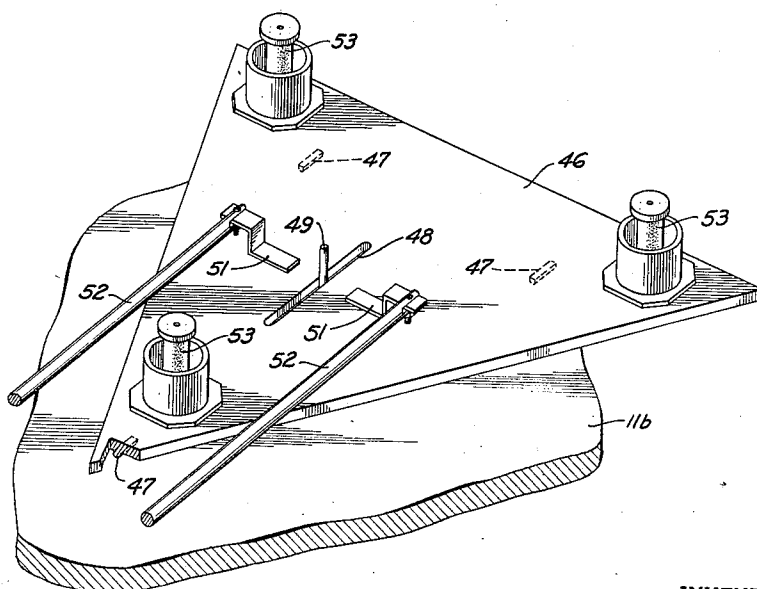


Fig 8

INVENTORS.
JOHN G. BACKUS
BERNARD PETERS
BY
Poland A. Anderson
ATTORNEY

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4 Sheets-Sheet 3

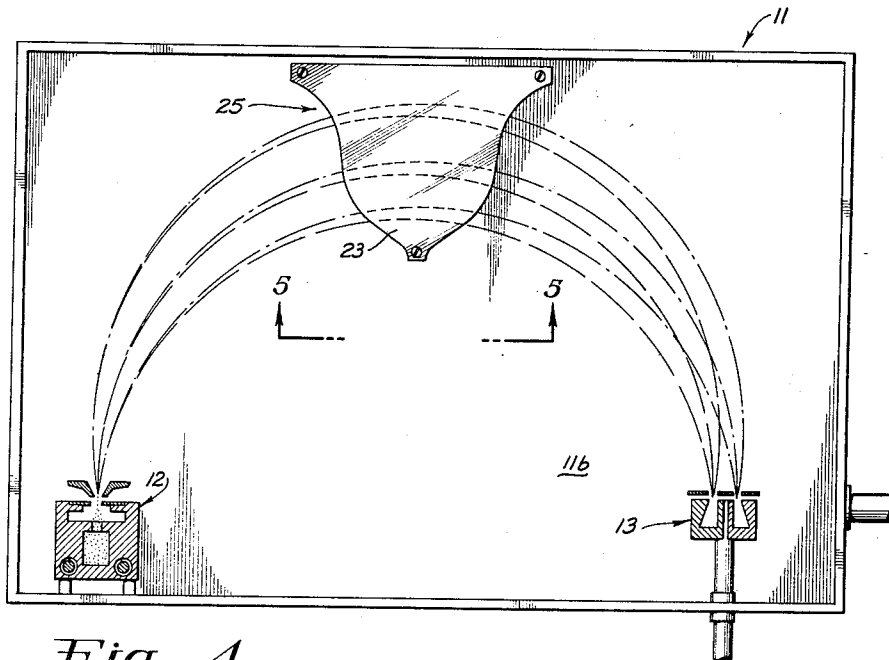


Fig. 4

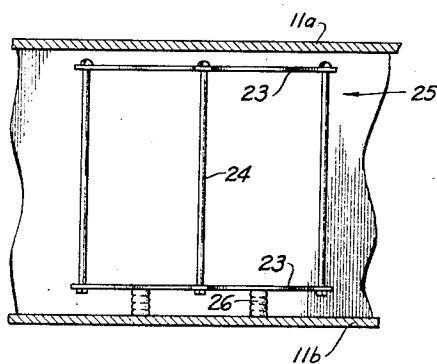


Fig. 5

INVENTORS.
JOHN G. BACKUS
BERNARD PETERS

BY

Roland A. Anderson

ATTORNEY

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4 Sheets-Sheet 4

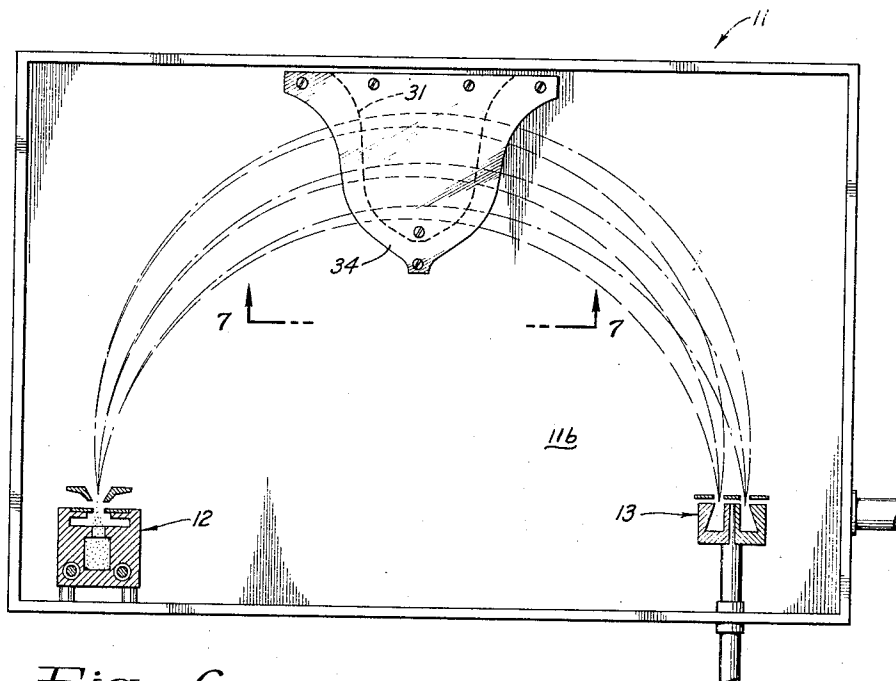


Fig. 6

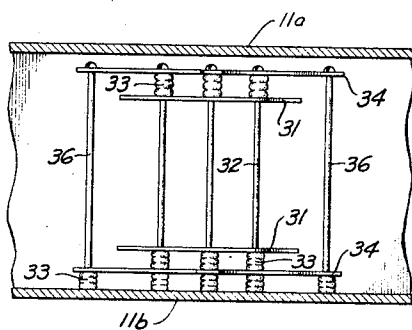


Fig. 7

INVENTORS.
JOHN G. BACKUS
BERNARD PETERS
BY
Roland A. Andersen
ATTORNEY

UNITED STATES PATENT OFFICE

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METHOD AND APPARATUS FOR FOCUSING
CHARGED PARTICLES

John G. Backus, Los Angeles, Calif., and Bernard
Peters, Rochester, N. Y., assignors to the United
States of America as represented by the United
States Atomic Energy Commission

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10 Claims. (Cl. 250—41.9)

1

This invention relates to the focusing of divergent beams of charged particles and more particularly relates to an improved method and means for electrostatically increasing the sharpness of foci of divergent ion beams in the electromagnetic separation of ions.

Electromagnetic apparatus for the separation of isotopes customarily utilize very high current ion beams. Such a beam is advantageously generated by a virtual line source parallel to the magnetic field; however, it has been found that a beam so generated has considerable divergence in a plane transverse to said magnetic field. Thus, although theoretical considerations may predict a satisfactory separation between the foci of two isotopes of an element, actually separation will be much less than calculated with the result that the ion beams may overlap in the region of their maximum separation. In order to realize the theoretical separation of the desired ion beams it is necessary to provide an arrangement which will divert the beams from their normal paths as determined by the magnetic and electric influences exerted by the electromagnetic apparatus, and will further sharply focus the ion beams in their region of maximum separation.

It is therefore an object of this invention to provide a new and improved method of and apparatus for improving the electromagnetic separation of isotopes by increasing the sharpness of foci of divergent arcuate ion beams.

It is a further object of this invention to provide a method and apparatus for improving the sharpness of foci of divergent arcuate ion beams in the electromagnetic separation of isotopes beyond the sharpness which can be obtained through the effect of the uniform magnetic field alone.

It is a further object of this invention to provide a method and apparatus for increasing the sharpness of foci of divergent arcuate ion beams by improved electrostatic focusing means.

It is further object of this invention to provide a method and apparatus for increasing the sharpness of foci of divergent arcuate ion beams by employing electrostatic fields passing transversely through the plane of the divergent arcuate ion beams.

It is still a further object of this invention to provide a method and apparatus for increasing the sharpness of foci of divergent arcuate ion beams by means of an electric refracting region employed in the path of the divergent arcuate ion beams.

It is a further object of this invention to pro-

2

vide a method and apparatus for increasing the sharpness of foci of divergent arcuate ion beams by means of an electric refracting surface curved in a manner of a lens and placed in the path of the divergent arcuate ion beams of an electromagnetic separator.

Another object of this invention is to provide a method and apparatus for improving the linearity of an electric lens by generating an equipotential surface along the common magnetic projection of the edges of multiple parallel-spaced electrodes.

Still a further object of this invention is to provide an improved electric lens system which may be adjusted angularly about an axis parallel to the magnetic field and adjusted slidably along a radius of an ion beam arc.

Other objects and advantages of the invention will be apparent from the following description and appended claims.

One manner in which the above objects may be realized and the invention may be most advantageously employed is fully set forth in the following description which may be best understood when considered with the accompanying drawings, in which:

Figure 1 is a plan view of an electromagnetic separator tank with the top plate removed and showing one embodiment of the invention consisting of the lower assembly of sets of strip shims comprising the linear type of electric lens;

Fig. 2 is a partial section of the separator tank with the top wall in place, taken as indicated by section line 2—2 of Fig. 1, and showing in further detail the linear shim type of electric lens;

Fig. 3 is a partial section of the separator tank taken as indicated by line 3—3 of Fig. 1, showing an assembly of strip shims and their electrical connections;

Fig. 4 is a plan view of a separator tank with the top plate removed showing another embodiment of the invention consisting of the prism type of electric lens;

Fig. 5 is a partial front elevational section of the separator tank taken as indicated by line 5—5 of Fig. 4 showing an embodiment consisting of two electrodes;

Fig. 6 is a plan view of a separator tank with the top plate removed showing positioned therein two lens systems of the prism type comprising one set of paired electrodes nested between a second set of paired electrodes;

Fig. 7 is a partial front elevational section of the embodiment of Fig. 7 taken as indicated by line 7—7 of Fig. 6; and

Fig. 8 is a perspective view of an adjustable lens mounting plate adaptable for use with the prism type of electric lens.

It is to be noted that in each of Figs. 1, 4, and 6 the ion beam is indicated by dotted lines emanating from an ion source and impinging upon an ion receiver; and also that the ion source and receiver are numbered 12 and 13, respectively. It will of course be appreciated that numerous types of ion sources and receivers may be utilized with electromagnetic separators and since many such types may be used without departing from the scope of this invention no further details of the source and receiver other than those shown in the drawings are presented herein.

Referring to Figs. 1, 2, and 3, there is illustrated a linear type of electric lens 10 suitable for incorporation in an electromagnetic isotope separator. An evacuated tank 11 having an ion source 12 and an ion receiver 13 positioned therein substantially as shown is located between the pole faces of a magnet (not shown) in such a manner that a uniform magnetic field passes through the tank 11, perpendicular to the top and bottom walls 11a and 11b, respectively, said magnetic field being directed upward from the plane of Fig. 1. Positioned on the rear of each of the top wall 11a and bottom wall 11b are electric strip shims 20 which are supported by brackets 19. The shim assembly comprises a plurality of parallel strips 20 electrically insulated from each other and mounted by means of insulators 21 on brackets 19. The upper and lower shim assemblies are so disposed that each upper strip 20 has its corresponding counterpart on the lower set arranged in the magnetic projection of the upper strip. Moreover, the strips 20 are connected through coupling arrangements 22 to the desired electrical potentials, each vertical pair of strips having a common projection along the magnetic field being maintained at the same electrical potential.

Considering the shim arrangement from left to right in Fig. 2, each successive pair of shims is connected to greater (or lesser) potentials than the pair preceding, the choice between increasing or decreasing potentials as well as the particular values and sign of the potentials being predetermined by design considerations. Thus a series of electrical fields of progressively varying intensities are established in the path of the ion beam, thereby producing a region of complex electrostatic fields of such magnitude and configuration as to divert the paths of ions of equal mass-to-charge ratios to a relatively sharp focus at the ion receiver.

Another embodiment of the present invention is illustrated in Figs. 4 and 5 showing an electric lens 25 of the prism type including a pair of identical plate electrodes or shims 23 which are separated from each other by conducting uprights 24. The bases of these shield-shaped plates extend along the rear wall of the tank, and the outer surfaces of the plates are respectively adjacent the top wall 11a and the bottom wall 11b of the tank 11. The lens structure, comprising plate-electrodes 23 and supporting uprights 24, is mounted on the bottom of the tank and insulated therefrom by insulators 26. An equipotential region is established between the plates 23 by the application of a potential to them. The magnetic field of the separator is perpendicular to the plates 23 and therefore constrains the equipotential region to extend only to the extremities of the plates 23. The entire potential drop be-

tween the tank potential and the equipotential region between the plates 23 occurs in a thin sheath of uniform thickness connecting the extremities of the plates 23. This sheath acts as a refracting surface, through which ions are refracted by Snell's law. The edges of the plates are given suitable shapes so that this property of refraction is utilized to correct the geometrical defocusing which occurs in the usual shimless tank. The suitable shape of the shim plates depends upon the design and operating characteristics of the particular electromagnetic isotope separator with which they are to be used, and may be determined either geometrically or analytically. In this respect it is to be noted that the shield-shaped electrodes of Fig. 4 represent only one possible configuration and that the actual shape for any particular application may vary considerably from that of a shield; one extremity of configuration being that similar to an hourglass (not shown).

The embodiment of the invention shown in Figures 4 and 5 may be further modified by the use of more than two identical electrodes. For example, three or more identical plate electrodes can be arranged in parallel relationship and may be supported as are the two electrodes shown in Fig. 5. This arrangement has the advantage of further reducing the tendency of the equipotential refracting surface to bow or digress from the vertical and of eliminating slight inhomogeneities possibly present in the refracting electric field; thereby providing an even more advantageous focusing action.

A further modification of the embodiment shown in Figures 4 and 5 is depicted in Figs. 6 and 7 wherein a small lens is nested in a larger lens. The small lens is defined by a pair of electrodes 31 positioned normal to the magnetic field and in parallel relation to each other with respect to the magnetic field. The electrodes 31 are spaced apart by conducting uprights 32 and this entire small lens assembly is symmetrically mounted by means of insulators 33 interior to a like lens assembly of larger proportions. The larger lens assembly comprises two electrodes 34 spaced apart by conducting uprights 36, the whole assembly being mounted on and insulated from the tank bottom 11b by insulators 33. Each of the lens assemblies has separate electrical connections to the tank exterior as shown, thereby providing a desirable flexibility in the operation thereof. If it is desired to operate both lenses, they are both electrically connected to the proper potential; however, if only the smaller lens is to be operated, it is connected to the desired potential and the larger lens electrically grounded to the tank 11.

The output of electromagnetic separators is commonly increased by providing therein a plurality of spaced ion sources together with correspondingly spaced receivers. It will be readily apparent that the focusing means of the present invention, both the linear type and the prism type, are equally applicable and advantageous regardless of the number of beams employed. When using a linear type of electric shims as illustrated in Fig. 1 together with a plurality of spaced ion sources and receivers, the same degree of focusing effect is imparted to each ion beam since the geometry of each ion beam in its arcuate traverse from its respective ion source, through the electrostatic region comprising the lens, to its respective receiver is identical. In the case of prism type shims the shape

of the shim edges is determined so that the desired amount of refraction is imparted to each beam.

In certain circumstances advantages lie in varying the position of an electric lens within an electromagnetic separator tank. There is illustrated in Fig. 8 means adaptable for use with the prism type lens whereby rotary motion and lateral motion of the lens may be produced by forces applied exterior to the tank proper. There is provided a base plate 46 having a plurality of projections 47 joined to the under surface thereof and having a slot 48 formed in the approximate center thereof as shown. The base plate 46 is positioned adjacent the bottom wall 11b of the tank 11 with the base plate projections bearing upon the bottom wall 11b in slidable relation thereto. An upright member such as a round peg 49 is rigidly joined to the bottom wall 11b in such position as to engage the slot 48 in the base plate 46, thereby enabling the base plate 46 to rotate about or slide along the peg 49 within the limits set by the size of the slot 48. The base plate 46 is also provided with a pair of brackets 51 rigidly joined to the upper surface thereof and positioned on opposite sides of the slot 48. A rod 52 is pin-connected to each of the brackets 51 as shown and both rods may be extended through a tank wall through the medium of seals, as for example seals of the Wilson type, so as to provide exterior means for moving the base plate 46. The base plate may be rotated about the peg 49 by the application of opposite forces to the rods 52 and may be slidably adjusted by means of equal forces to the rods 52. A number of insulators 53 are mounted upon the upper surface of the base plate 46 and any desired lens assembly such as described above is mounted upon the insulators 53. Thus there is provided exterior to the tank of an electromagnetic separator means to adjust the position of a prism type lens with the latitude of angular adjustment in the plane of ion travel and slidable adjustment along a radius of the ion beam arc.

With reference to the operation of electromagnetic separators, it may be stated in general that ions are formed at a source and forceably ejected therefrom with a velocity in one general direction. These ions then pass into a plasma region and under the influence of a magnetic field acting therethrough are separated into a number of ion beams composed of ions of like mass-to-charge ratios. These ion beams traverse arcuate paths to generally separate foci at a receiver. The present invention as disclosed above provides an improved method and apparatus for refracting these beams a desired amount whereby each beam is individually sharply focused at a receiver. Thus the attendant defocusing effect of the magnetic field is eliminated and a more complete and efficient separation may be realized by the utilization of the present invention.

While the salient features of the present invention have been described in detail with respect to particular embodiments, it will of course be apparent that numerous modifications may be made within the spirit and scope of the invention, and it is therefore not intended to limit the invention to the exact details shown except insofar as they may be defined in the following claims.

What is claimed is:

1. In an electromagnetic separator device comprising in combination a transmitter and a receiver and having means establishing a mag-

netic field constraining ions emitted from said transmitter to traverse arcuate paths; electrostatic focusing means including a plurality of parallel spaced electrodes lying in planes parallel to said ion traverses, and electrical supply means applying electrical potentials to said electrodes whereby equipotential refracting surfaces are established normal to the plane of and in the path of said ion traverses whereby said ions are influenced to converge at foci.

2. In an electromagnetic separator comprising an evacuated tank, a magnetic field passing through said tank, an ion source, and a divergent arcuate beam of ions propagated from said ion source into said tank transverse to said magnetic field; at least one deflecting member disposed on each side of said ion beam in planes substantially parallel to the plane of the ion beam traverse, said deflecting elements being oriented with the projection of adjacent edges of said members corresponding and intersecting said ion beam normal to the plane of the ion beam traverse, and means impressing a potential upon said elements to deflect said ion beam.

3. In an electromagnetic separator comprising an evacuated tank, a magnetic field passing through said tank, an ion source, an ion receiver, a divergent beam of ions propagated from said source into said tank transverse to said magnetic field whereby said ions traverse arcuate paths; electrostatic deflecting members disposed on opposite sides of said ion beam in planes substantially parallel to the plane of the ion beam traverse, the projection of adjacent edges of said members coinciding in perpendicular relationship to the plane of said ion beam traverse, and means impressing potentials upon said members to define electrostatic surfaces intersecting said ion beam whereby ions having equal mass-to-charge ratios are directed to a common focus.

4. In an electromagnetic isotope separator comprising an evacuated tank, a magnetic field through said tank, an ion source, an ion receiver, and a divergent beam of ions propagated from said source into said tank transverse to said magnetic field, whereby said ions traverse arcuate paths; a plurality of electrodes arranged in said tank with the edges of said electrodes having a common projection along said magnetic field intercepting said ion beam, and means for applying a potential to said electrodes whereby ions having equal mass-to-charge ratios are projected toward a focus.

5. In a device employing electromagnetic means for the separation of ions or isotopes comprising an evacuated tank, a magnetic field passing through said tank, an ion source, an ion receiver, a divergent beam of ions propagated from said source into said tank transverse to said magnetic field whereby said ions traverse arcuate paths; an arrangement of electrodes disposed in said tank defining an electrostatic refracting region established in the path of said ion beam, said refracting region comprised of substantially parallel planar equipotential surfaces lying along the direction of said magnetic field whereby additional to the focusing effect of the magnetic field, ions having equal mass-to-charge ratios are directed toward a common focus.

6. In a device employing electromagnetic means for the separation of ions or isotopes comprising an evacuated tank, a magnetic field passing through said tank, an ion source, an ion receiver, a divergent beam of ions propagated from said source into said tank transverse to said mag-

netic field whereby said ions traverse arcuate paths; two multiple sets of electrodes, the first set comprising one or more parallel-spaced coplanar linear strip electrodes disposed adjacent and parallel to one planar side of the arcuate ion beam, the second set being identical with said first set and having counterpart linear strip electrodes arranged in the common magnetic projection of the strip electrodes comprising said first set and furthermore being similarly disposed adjacent and parallel to the planar side of the arcuate ion beam opposite said first set, corresponding counterpart successive adjacent strip electrodes of both sets being connected to the same sources of electrical potentials, whereby an electrostatic refracting region is established in the ion beam plasma diverting ions having equal mass-to-charge ratios to a common focus.

7. In an electromagnetic device comprising an evacuated tank, a magnetic field passing through said tank, an ion source, an ion receiver, and a divergent beam of ions propagated from said source into said tank transverse to said magnetic field whereby said ions traverse arcuate paths; a plurality of electrodes having arcuate edges arranged in said tank, said edges having a common projection along said magnetic field intercepting said ion beam, and means for applying a potential to said electrodes whereby ions having equal mass-to-charge ratios are directed to a focus.

8. In an electromagnetic device comprising an evacuated tank, a magnetic field passing through said tank, an ion source, an ion receiver, and a divergent beam of ions propagated from said source into said tank transverse to said magnetic field whereby said ions traverse arcuate paths; a pair of electrodes having arcuate edges arranged in said tank and a smaller pair of electrodes of substantially similar shape nested between said first pair of electrodes, each pair of electrodes having their arcuate edges respectively on a common projection along said magnetic field, means for applying potentials to each pair of said electrodes independently, where-

by selection may be effected of either a large electrostatic focusing surface or a relatively smaller focusing surface, said focusing surface intercepting said ion beam, thereby directing ions having equal mass-to-charge ratios to a focus.

9. In an electromagnetic device comprising an evacuated tank, a magnetic field passing through said tank, an ion source, an ion receiver, and a divergent beam of ions propagated from said source into said tank transverse to said magnetic field whereby said ions traverse arcuate paths; an electrostatic focusing assembly of electrodes arranged in said tank, said assembly of electrodes being angularly adjustable in the plane of said ion beam arc and slidably adjustable along a radius of said ion beam arc, and adjusting means for said assembly whereby said adjustments may be effected exterior of said tank in order to insure that ions having equal mass-to-charge ratios are directed to a focus.

10. In an electromagnetic isotope separator comprising an evacuated tank, a magnetic field through said tank, an ion source, an ion receiver, and a beam of ions projected from said source into said tank transverse to said magnetic field whereby said ion beam is constrained to traverse a path toward said receiver; a plurality of electrostatic deflecting members disposed symmetrically about said ion beam transverse with the common projection of adjacent edges of said members intersecting said ion beam transverse normal to the plane thereof, and means impressing a potential upon said members to produce electrostatic equipotential surfaces directed by the common projection of adjacent edges of said deflecting members whereby said beam of ions is deflected from its normal traverse.

JOHN G. BACKUS.
BERNARD PETERS.

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