Fig. 1

Fig. 2

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Fig. 3

magnetic field

A'  l'_{mr}  a_{m} \phi_{m}  \theta_{m}  D  a_{e} \phi_{e}  l''_{ez}  A''

l'_{mz}  \theta_{mz}  l'_{er}

electric field

A'  l''_{mr}  A''

Fig. 7

magnetic field

A'  l'_{mr}  a_{m} \phi_{m}  \theta_{mz}  D  a_{e} \phi_{e}  l''_{ez}  A''

l'_{mz}  a_{m} \phi_{m}  \theta_{mz}  A''

electric field

A'  l''_{mr}  A''

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DOUBLE DEFLECTION SYSTEM FOR FOCUSING IONS OF SELECTED MASS AND CHARGE AT A PREDETERMINED POINT

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4 Claims. (Cl. 258—41.9)

The present invention relates to mass spectrographs of the paraboloid type, wherein mass and energy separation of ions is accomplished by a predetermined parabola.

In paraboloid spectrographs, ions traverse electrostatic and magnetic deflection fields, whereby the depletions as produced by the two fields are oriented perpendicular to each other and to a medium ion beam path. The thus separated ions can be intercepted in a plane extending transversely to the beam. Ions of a particular mass m traverse this plane (or being absorbed therein) along a paraboloid. Ions of similar mass but different kinetic energy arrive at different points on this paraboloid. Ions of different mass define a different paraboloid.

Thus, such paraboloid spectrograph is simultaneously an energy as well as mass spectrograph. Actually, it is an ideal paraboloid apparatus. However, such paraboloid spectrographs are not often being used. The reason is that the fields only deflect and separate, but they do not focus. In order to attain sufficient resolving power, the ions have to travel through a collimator path comprising of two spaced diaphragms with narrow and aligned apertures. A device resembles a camera obscura, the most simple kind of photographic apparatus. In order to produce a sharp image of any object point, the aperture must be very narrow indeed. Of course, the amount of light available for such a camera is very small and thus requires exceedingly long exposure times are required. Precisely the same disadvantage is observed at the aforementioned paraboloid spectrographs.

It is an object of the present invention to provide a new and improved focusing paraboloid spectrograph.

It is another object of the present invention to focus the ion beam entering a paraboloid spectrograph through a single diaphragm aperture so that the width of the paraboloid is approximately of the same size as the diameter of the diaphragm aperture.

According to one aspect of the present invention in a preferred embodiment thereof, it is suggested to provide the following arrangement taken along the ion travel path, beginning at the ion source (entrance diaphragm aperture).

There is first a pair of pole shoes defining a magnetic field, preferably a homogeneous one as to curve the travel path of the ion ray. The two shoes have and define an entrance plane and an exit plane, oriented parallel to the axis of path-curvature, and being inclined to each other. The inclination preferably is an adjustable one. There is a plane of symmetry defined between the two pole shoes, which is oriented transversely to the axis of curvature of the ion beam travel path.

Next there is a pair of electrode plates either of cylindrical or toroidal shape. The plates setup an electrostatic field and they have a curvature so that the center of the deflected ion beam travels along a medium equipotential surface setup between the plates. The plane defined by this curved center ray is parallel to the electric field but is transverse to the said plane of symmetry of said pole shoes.

While the specification concludes with claims particularly pointing out and distinctly claiming the subject matter which is regarded as the invention, it is believed that the invention, the objects, and features of the invention and further objects, features and advantages thereof will be better understood from the following description taken in connection with the accompanying drawing in which:

FIGURE 1 illustrates schematically and in a perspective view a principle elements and features of a known paraboloid spectrograph;

FIGURE 2 illustrates schematically the basic features of the inventive focusing paraboloid spectrograph with FIGURE 2a being a top and FIGURE 2b a side elevation;

FIGURE 3 illustrates schematically the focusing effect produced with the apparatus shown in FIGURE 2;

FIGURE 4 illustrates an adjustable pole shoe arrangement for the magnetic deflection system of the inventive paraboloid spectrographs;

FIGURES 5 and 6 illustrate paraboloids attained photographically with the inventive spectrograph;

FIGURE 7 illustrates schematically a modification of the focusing produced in case a toroid electrode system for the electrostatic field is being used;

FIGURE 8 illustrates schematically a complete focusing paraboloid spectrograph according to the invention; and

FIGURE 8a illustrates a 90° displaced view of the right-hand portion of FIGURE 8.

For purposes of a general orientation, the principles involved in the known, nonfocusing paraboloid spectrograph shall be explained briefly with reference to FIGURE 1.

There are shown two magnetic poles S and N producing in-between a (ideally assumed) homogeneous magnetic field. A pair of electrode plates respectively connected to plus and minus pole of an electric voltage source superimposes a parallel, homogeneous electrostatic field upon the said magnetic field.

An ion beam 20 enters the two fields perpendicularly to the direction of the respective field lines. If no magnetic and no electrostatic field were there, the ion beam 20 would proceed as indicated by the dashed line 20' and meet a plane 21 at the origin of a coordinate system x-y. Plane 21 is perpendicular to line 20'. There may be positioned a photographic plate or the like in this plane 21, i.e., plane 21 may be part of such plate which is responsive to the ion beam.

The electric field E as resulting from a difference in potential as applied to electrode plates will deflect the ion beam at an angle of

\[ \theta = \frac{eEL}{mv^2} \]

wherein \( e \) is the charge of the ion, which is either the elementary charge or an integral multiple thereof, \( m \) and \( v \) are mass and speed, respectively of the ions and \( L \) is the length of the electrode plates measured in the direction of undisturbed ion propagation. Assuming that the pole shoes and thus the width of the magnetic field is of the same length \( L \), and producing a magnetic induction \( B \), the ion ray will be deflected by an angle determined to

\[ \theta = \frac{eBL}{mv} \]
These deflections, however, do not occur in the same plane, but the magnetic deflection occurs in the direction \( y \) as defined, whereas the electrostatic deflection occurs in the direction \( x \). Orientation is determined by the relative position of magnetic north and south pole, and the specific potential level applied to any of the electrode plates.

The distance between the exit of the two fields and the projection plane 21 be \( l \) so that \( x=l\cdot \tan \alpha \) and \( y=l\cdot \tan \alpha \) hence

\[
z = l \cdot \frac{E_L}{m \cdot v^2}
\]

\[
y = l \cdot \frac{B_L}{m \cdot v}
\]

elimination of speed \( v \) from the two equations results in the parabola equation

\[
y^2 = C \cdot \frac{e}{m} \cdot z
\]

wherein \( C \) is a constant including the apparatus data \( l, E \) and \( B \).

For ions of similar \( e/m \) value, but having different speeds, the beam is being spread so as to form the parabola 22 on screen plane 21. In case of uniform ionization, the parabola includes, of course, particles of similar mass.

Particles of different \( e/m \) ratios form different parabolas. Points pertaining to different parabolas but forming or defining a line parallel to axis \( x \) (\( x \) being constant) result from particles having similar energy

\[
\frac{m}{Z^2} \cdot E
\]

(though different mass), and points forming a line parallel to axis \( x \) (\( y \) being constant) result from particles having similar impulse \( mv \).

With reference to FIGURES 2 and 6 it now shall be explained and described in principle that by suitably forming sectorial deflecting fields it is possible to not only deflect and spread particles to parabola points, but to focus the particles in both directions, \( x \) and \( y \) as defined.

It would be very difficult both from practical as well as from theoretical standpoint, to superimpose electrical and magnetic sectorial fields at the same location. It is simpler and therefore better to place the sectorial fields in series along the ray travel path but at a short distance from each other.

Basically it appears unimportant in which succession the fields are placed, but it has been found more practical to have the ion beam pass the magnetic field first and then the electrical field. (See Ewald and Neumann Fokussierende Parabelspektrographen, Zeitschrift für Physik, volume 169 (1953), page 224 (226, 227)). The magnetic field can be either homogeneous or inhomogeneous, and the electrostatic field can be produced by a pair of concentrically cylindrical electrode plates or by a toroidal condenser (see for example, Patent 3,061,720).

FIGURE 8 illustrates a schematic view of a complete spectograph, certain details thereof will be more fully explained with reference to FIGURES 2 and 4.

There is first a gas inlet pipe 1 constituting part of an anode structure of an ion producing and, accelerating system which includes the cathode 3, separated electrically by means of an insulating anulus. The chamber 2 including cathode and anode defines an electron collision or impact type ion source. The cathode 3 has an aperture through which pass ions accelerated at an adjustable voltage of 25 kilovolts. This part is of conventional design.

The ions passing through cathode 3 enter a tubular aluminum casing 14 which is connected to two oil diffusion pumps 5. There is provided an additional ionization chamber inside of casing 14, which chamber is devised to investigate collision dissociation of ions. This chamber is comprised of a tube 15 being about 6 cm. long with an inner diameter of about 3 mm. The ion beam passes through tube 15 in axial direction. By means of a valve (not shown) and a thin copper pipe 6 gas may enter this collision chamber.

In further direction along the ion beam path, particularly at the exit side of pipe 15, there is positioned a horizontally slidable inlet diaphragm 7. One may use a diaphragm holder of conventional design supporting several diaphragms of different diameters and a selected one can be placed into the path. The inventive apparatus has been built with a 0.3 mm. and a 0.05 mm. diaphragm. This diaphragm is the main particle entrance for the spectrograph and actually defines the "ion source" within the meaning of the following: For limiting the conical dimension of the beam, a second diaphragm 8 is placed into the beam path having a diameter of 2 mm. aperture.

This diaphragm is preferably made adjustable in both, horizontal and vertical directions; also diaphragm 8 can be removed entirely, since it is not essential for the basic function.

Proceeding along the ion beam path, at the end of casing 14 there is attached (for example, screwed) a flat vacuum tube 11 of high grade steel having a flange 13n is attached therewith and at an angle to the end of casing 14. Tube 11 is positioned in the air gap of the deflection magnet 10. The field lines are perpendicular to the plane of the drawing. Adjacent the entrance to the magnetic field there is a stray field diaphragm 9 having an aperture of 5 mm. This diaphragm 9 is secured to the flange 11a of tube 11 in the air gap.

The magnet 10 is of the horseshoe type with the poles being apart by 13 mm. A pivoting pole shoe portion 16 of the magnet at the exit thereof enables adjustment of the exit angle of the beam by ±10°. This will be more fully explained with reference to FIGURE 4 below. No stray field diaphragm is provided at the exit side of the magnet. The magnet has a low ohmic coil feed with current up to 8 amperes. There is preferably a power supply regulator (not shown) stabilizing the supply voltage for the magnet within 1%.

Reference numeral 12 designates the electrostatic deflection system comprising the cylindrical electrode plates 12a and 12b for producing electrical deflection. Plates 12a and 12b are housed in an aluminum pipe 17 contiguous with tube 11 but of larger diameter. The electrode plates are so constructed and positioned that the entrance plane for the beam is exactly perpendicular to the center line or ray.

One can further see from FIGURES 8 and 8a, that pipe 17 is attached to tube 11 at an angle to accommodate the beam deflection by the electrostatic deflection system occurring transversely to the magnetic deflection.

A brass pipe 18 secured to the aluminum pipe 17 contains the photoplate 13 adjustable positioned therein. A ball bearing at the photoplate supporting element enables tilting of photoplate 13 relative to the center line or ray.

Details and function of the electrostatic and the magnetic deflection systems will now be explained with reference to FIGURES 2 and 3.

FIGURE 2 is actually composed of two portions, 2a and 2b, wherein 2a can be constructed as top view (corresponding to the view of FIGURE 8) and 2b as side elevation. Better, however, it is to say, that the plane of the drawing for FIGURE 2a is a plane extending transversely to axis 30 of the magnetic deflection, whereas the plane of the drawing of FIGURE 2b is a plane which is extending transversely to the axis 33 for the electrostatic deflection of the ion beam.

The beam 25 is assumed to be of uniform mass and energy (speed).

Thus, FIGURE 2a shows the radial travel path component of the ion beam in the magnetic field and the axial component in the electrical field, whereas FIGURE 2b shows the axial component of the ion beam in the
magnetic field and radial component in the electric field.

The ions are assumed to emanate from a point source \( A' \), which is FIGURE 8 is diagram 7, and from com-
parison of FIGURES 2a and 2b one can see, that the ions form a conical beam having its apex at \( A' \) and having a
center line or ray 26.

Reference numeral 10 again designates the magnetic deflection system having pole shoes 10a and 10b and
setting up a magnetic sector field having an entrance plane of \( 0^\circ \). Setting parallel to the plane of the drawing
of FIGURE 2a. Center line or ray 26 enters the mag-
netic deflection system perpendicularly to plane 27 and
thus defines an entrance angle \( \epsilon = 0 \).

The center line or ray 26 leaves the magnetic deflection
system 10 at an exit angle \( \epsilon' = 0 \). The exit plane 28 of
system 10 is also perpendicular to the plane of the draw-
ing 2a, but this exit plane is inclined by this specific angle
\( \epsilon'' \) to the plane of the drawing of FIGURE 2b. The def-
lection angle \( \epsilon'' \) of liner or ray 26 is measured negative.
The entrance and exit angles \( \epsilon' \) and \( \epsilon'' \), respectively of the various portions of the beam are considered positive, whenever the respective entrance and exit normal direc-
tions appear on one side of the center line or ray and
the magnetic deflection center (here 30) is on the other
side. Since in FIGURE 2a the exit normal is on the same
side as is center 30 relative to the leaving center line or ray, this angle \( \epsilon'' \) here to be considered of negative
value.

The distance between source \( A' \) and the entrance plane
27 is designated by \( r_{mz} \). \( \phi_0 \) is the angle of total def-
lection of center line or ray 26 in the magnetic deflection
system 10 with \( a_{mz} \) being the radius of curvature of this
center line or ray during magnetic deflection. Since the
magnetic field is assumed homogeneous and constant, \( a_{mz} \)
is constant indeed. Planes 27 and 28 extend parallel to the
field lines between the pole shoes 10a and 10b, there
being a plane of symmetry between the pole shoes trans-
versely oriented to the field lines and said planes 27, 28.

The beam leaving the magnetic deflection system now
enters the electrostatic deflection system 12 comprised of
two cylindrically shaped electrode plates 12a and 12b.
The two plates 12a and 12b are concentrically disposed with
33 being the common axis. \( \phi_0 \) designates the angular
width of the two plates and \( a_{mz} \) is the radius of curvature
of the ion center line or ray 26. This center line or ray
runs along an equipotential surface between plates 12a
and 12b, and it defines a plane of curvature extending
perpendicularly to the plane of symmetry of pole shoes
10a and 10b. This latter plane of symmetry can also be
considered as coinciding with the line used to designate
center line or ray 26 in FIGURE 2b.

\( D \) designates the distance between center line or ray
exit of the magnetic deflection system (which is the spot
where line or ray 26 traverses plane 28) and the entrance
plane of the electrostatic deflection system. The beam
appears focused at point \( A'' \) in a plane 29 spaced at a
distance \( l''_{mz} \) from the exit plane of the electrostatic
deflection system.

Since presently the focusing produced by this arrange-
ment is of primary interest, the focusing itself will best
be described with reference to the simplified schematic
illustration of FIGURE 3. The simplification is had in
that the center line or ray 26 is drawn as a straight line
so as to illustrate only the specific focusing of the conical
beam 25 of FIGURE 2. Thus, to revert to reality, the
magnetic and electric deflection (\( \phi_0 \) and \( a_{mz} \)) produced for
the center line or ray 26 has simply to be superimposed
upon the several rays of FIGURE 3.

FIGURE 3 is also composed of two portions, FIGURES
3a and 3b, which means that FIGURE 3a corresponds to
FIGURE 2a with origin 30 removed to infinity, and
FIGURE 3b corresponds to FIGURE 2b but with origin
33 assumed to be in infinity so that the center line or ray
26 appears as if it is undeflected by either deflection
system.

The various exit and entrance planes of the deflection
systems now appear as vertical lines in FIGURE 3a and
FIGURE 3b. FIGURE 3a shows specifically the radial
focusing effect of the magnetic field, whereas FIGURE 3b
shows the radial effect produced by the electrostatic
field, as well as the axial focusing produced by the mag-
netic field. The last mentioned axial focusing is specif-
ically produced by the magnetic stray field at exit and en-
trance of the magnetic deflection system with \( \epsilon' = 0 \).

Phys. Aust. 4, 431 (1951) has described that these stray
fields act like thin axial cylinder lenses having focal
lengths

\[
f' = \frac{a_{mz}}{\tan \epsilon'}
\]

\[
f'' = \frac{a_{mz}}{\tan \epsilon''}
\]

at entrance and exit, respectively, of a magnetic deflection
system in general. Since instantly only \( \epsilon' = 0 \), only
the exit surface 29 produces such a focusing effect. (Dashed
line in FIGURE 3b.)

FIGURE 3 permits to write the following equations.

\[
f'' = f' + l_{mz} - D - a_{mz} \phi_0
\]

\[
l_{mz} = l_{mz} - D
\]

Here \( l_{mz} \) appears as the radial focal length of the mag-
netic field, \( D \) is the aforementioned distance between the
two deflection systems measured along the travel path of
the center line or ray. \( a_{mz} \) is the length of the center
ray travel path in-between the pole shoes and \( a_{mz} \) is the
corresponding length between the electrodes. The dis-
tance \( f'' \) is the focal length as produced by the elec-
trical system measured from the exit plane thereof.

\( f' \) is the radial focal length at the object side of the
electrostatic deflection system. Again, \( l_{mz} \) can be calculated
applying twice the lens equation simplified for thin lenses in
geometric optics

\[
f_{mz} = \frac{a_{mz} \tan \epsilon' \tan \epsilon''}{\tan \epsilon' + \tan \epsilon''}
\]

\[
I''_{mz} = I''_{mz} - D - a_{mz} \phi_0
\]

In order to calculate the necessary geometrical data for
the arrangement and design of the deflection systems, the
known radial lens equation for magnetic and electrical
sector fields are applied.

\[
I''_{mz} = I''_{mz} - g''_{mz} = f''_{mz}
\]

\[
I''_{mz} = I''_{mz} - \phi_0
\]

wherein the following abbreviations are being used:

\[
g_{mz} = \frac{a_{mz} \cos \epsilon' \cos \epsilon''}{\sin (\phi_0 - \epsilon' - \epsilon'')}
\]

\[
g''_{mz} = \frac{a_{mz} \cos \epsilon' \cos \epsilon''}{\sin (\phi_0 - \epsilon' - \epsilon'')}
\]

\[
J_{mz} = \frac{a_{mz} \cos \epsilon' \cos \epsilon''}{\sin (\phi_0 - \epsilon' - \epsilon'')}
\]

\[
J''_{mz} = \frac{a_{mz} \cos \epsilon' \cos \epsilon''}{\sin (\phi_0 - \epsilon' - \epsilon'')}
\]

\[
\alpha_\phi = \frac{a_{mz}}{\sqrt{2}}
\]

\[
f''_{mz} = \frac{a_{mz}}{\sqrt{2} \sin \phi_0}
\]

There are altogether the following twelve variable
components \( l_{mz} = l_{mz} - \phi_0 \), \( a_{mz} \), \( l''_{mz} \), \( l''_{mz} \), \( D\), \( l''_{mz} \), \( a_{mz} \), \( f''_{mz} \), \( f''_{mz} \), \( l''_{mz} \), \( a_{mz} \), all having been defined above and are explained
with reference to FIGURES 2 and 3.

The Equations 8, 9, 10, 11 and 12 are five conditions as
between these twelve variables, so that one can the find
seven variables in the most suitable manner. After hav-
ing selected such seven values, the aforementioned equa-
tions produce the remaining five values.
An apparatus as illustrated in FIGURE 8 has been constructed having approximately the following data. Preliminarily, the following seven values were selected: 

\[ l_{\text{air}} = l_{\text{gas}} = 450 \text{ mm} \]
\[ a_{\text{gas}} = 160 \text{ mm} \]
\[ \phi_{\text{gas}} = 36^\circ \]
\[ \epsilon' = 0^\circ \]
\[ D = 37 \text{ mm} \]
\[ a_{\text{gas}} = 148.5 \text{ mm} \]
\[ \phi_{\text{gas}} = 38.9^\circ \]

And with the aid of the five above listed equations, there resulted:

\[ l'_{\text{air}} = 279 \text{ mm} \]
\[ l'_{\text{gas}} = 254 \text{ mm} \]
\[ l''_{\text{air}} = 147 \text{ mm} \]
\[ \epsilon'' = -15.8^\circ \]
\[ v_{\text{air}} = 291 \text{ mm} \]

Upon operating this apparatus, an entrance diaphragm (7 in FIGURE 8) was employed having an opening of .05 mm. diameter. A mass resolving power of 2500 and a correspondingly defined energy resolving power of 5000 was produced matching exactly theoretical predictions. The theory regarding the mass and energy resolving power is described in our aforementioned paper (Z.f.Phr.) Vol. 169, pages 237, 238. No known parabola spectograph has yielded such resolving power. For photographically proving the existence of the parabolas, the exposure time was about 1 second. Smaller diaphragms will likely result in still considerably larger values for the resolving power.

The adjusting of the apparatus can be carried out in the following rather simpler manner, which will be explained with reference to FIGURE 4. There are shown pivotable, semicylindrical sections 16a and 16b at the exit of the magnetic deflection system for actually deflection, the exit plane 28 for determining the optimum value of angle \( \epsilon' \). This plane is defined by coplanar surface portions 16b and 16a. A similar arrangement (or substitute) may be had at the entrance of the magnetic deflection system to adjust \( \epsilon' \). Upon pivoting such elements, both radial and axial focal lengths at the image side vary but in opposite directions, so that relatively small pivot angles are required only for adjustment. In our aforementioned paper (Z.f.Phr. Vol. 169) on pages 234 and 235 there are described some quantitative results of the tilting of plane 28. Also, the effect of varying the electrostatic field is described therein.

Proceeding now to describe specific results obtained with the aforementioned apparatus, an ion source was employed wherein electrons collide with atoms to produce the ions (chamber 2 in FIGURE 8—no gas introduced through pipe 6). In such a case the energy spectrum is rather small so that only a small section of a parabola will be observed. FIGURE 5 is a reproduction of a photographic picture wherein multiples at mass numbers 14, 16 and 27 have been photographed close to each other while the fields were varied. The length of the lines correspond to the energy range of the ion source employed.

FIGURE 6 illustrates a relatively broad energy band of \( H^+ \) ions resulting by impact dissociation for \( H_2^+ \) ions. The latter were also taken from the electron impact ion source. The \( H_2^+ \) ions were fed to the chamber as defined by pipe 18 in FIGURE 8 filled with slightly pressurized xenon. The ions then were discharged towards the narrow diaphragm 7 constituting source A' in FIGURE 2. Since for every ionization there is actually involved a three particle collision, the ions produced secondarily by collision dissociation are not even approximately monoenergetic. This is the reason for the large energy range depicted in FIGURE 6.

In our paper mentioned above (Z.f.Phr., Vol. 169, supra) pages 232 and 233 further results obtained with the inventive spectograph are described.

The aforesaid parabola spectograph produces first order focusing. However, focusing of a higher order in both directions is indeed conceivable. Here it becomes necessary to provide for curved magnetic field exits and entrances. In lieu of the cylinder condenser as electrical deflecting system, a toroidal condenser has to be used. The distance between the electrodes constituting a pair of deflecting condensers can be selected sufficiently large so that a considerable portion of the entire energy spectrum (up to 20%) can be detected in one picture. Hence, such spectographs are particularly suited for investigating energy and mass spectrum of high energy particles, for example, fission products of heavy elements. The particles can emanate from thin layers and be charged into the spectograph at their high initial energy. If the photosensitive plate is substituted by a narrow diaphragm, an electrical particle scanner or counter can be placed behind the diaphragm opening. In this case the apparatus is modified to constitute a spectrometer.

In case a toroidal condenser is used in lieu of the cylindrical electrodes aforesaid, the axial focusing thereof is also to be considered. For a toroidal condenser we refer to U.S. Letters Patent issued to one of us, 3,061,720. This is to be explained with reference to FIGURE 7. The calculation is similar as aforesaid, but Equation 8 is to be substituted by the equation

\[ \frac{f_{\text{air}}}{f_{\text{gas}}} = R_{\text{gas}} \]

wherein \( R_{\text{gas}} \) is the radial axis of curvature of the center equipotential surface between the electrodes of the toroidal condenser. (See also Patent 3,061,720 in FIGURE 5.) \( a_{\text{gas}} \) is the corresponding radial radius of curvature of this equipotential surface, which is equal to the radius of curvature of the center ray in the electrostatic deflection field. It can be seen that the Equations 18 and 19 include cylinder condenser as special case with \( R_{\text{gas}} \to \infty \).

Using a toroidal condenser requires that the axial lens equation be taken under consideration which is

\[ \left( f_{\text{air}} - f_{\text{gas}} \right) \left( v'_{\text{air}} - v'_{\text{gas}} \right) = f_{\text{gas}} \]

using the following abbreviations:

\[ a_{\text{gas}} = \frac{a_{\text{gas}}}{\sqrt{c}} \tan \sqrt{c} \phi_{\text{gas}} \]

\[ f_{\text{gas}} = -\frac{a_{\text{gas}}}{\sqrt{c}} \sin \sqrt{c} \phi_{\text{gas}} \]

\[ c = a_{\text{gas}}/R_{\text{gas}} \]

The number of arbitrarily selectable variables is now larger by two; namely, \( f_{\text{gas}} \) and \( R_{\text{gas}} \). The invention is not limited to the embodiments described above but all changes and modifications thereof not constituting departures from the spirit and scope of the invention are intended to be covered by the following claims.

We claim:

1. In a mass spectroscope; spaced magnetic pole shoes establishing therebetween a substantially uniform magnetic field for deflecting an ion beam in a plane of magnetic deflection, condenser plate means establishing an electrostatic field for deflecting the ion beam in a plane of electrostatic deflection, said deflection planes are perpendicular to each other wherein the magnetic field and the electrostatic field are arranged in sequence along the path of the beam such that the particles first pass through the magnetic field and subsequently pass through the
electrostatic field, said pole shoes having mutually inclined entry and exit surfaces of the magnetic field so as to form a sector magnetic field to focus ions of like mass and energy in said plane of magnetic deflection at a predetermined point a certain distance beyond the field combination in the direction of ion travel, said condenser plate means providing the electrostatic field defined by inner and outer boundaries of an arcuate passage through which the beam travels and forming an electrostatic sector field to focus ions of the mentioned mass and energy in said plane of electrostatic deflection at said predetermined point, whereby said fields together provide stigmatic point focusing for these ions.

2. A mass spectroscope according to claim 1 which includes collimating means situated between an ion beam source and the magnetic field provided with a single entry iris.

3. A mass spectroscope according to claim 1 wherein the said magnetic pole shoes are electromagnets provided with part cylindrical, rotatable inserts which enable the mutual inclination of the entry and exit surfaces at an adjustable angle.

4. A mass spectroscope according to claim 1 wherein the condenser plate means are cylindrical.

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