Nov. 12, 1940. W. BLEAKNEY 2,221,467

FOCUSING AND SEPARATION OF CHARGED PARTICLES

Filed Dec. 27, 1938 4 Sheets-Sheet 1

Fig. 1.

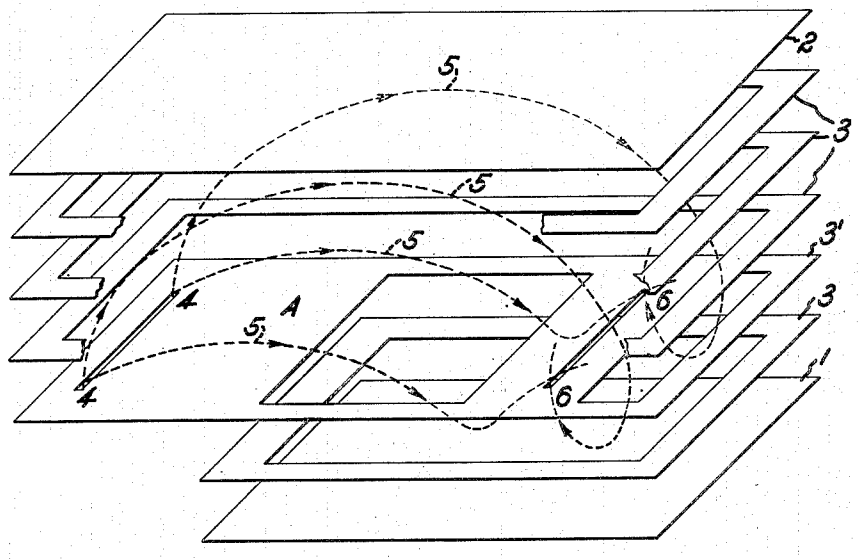


Fig. 1a.

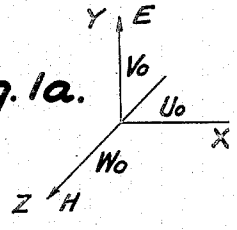


Fig. 1c.

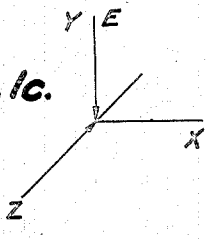
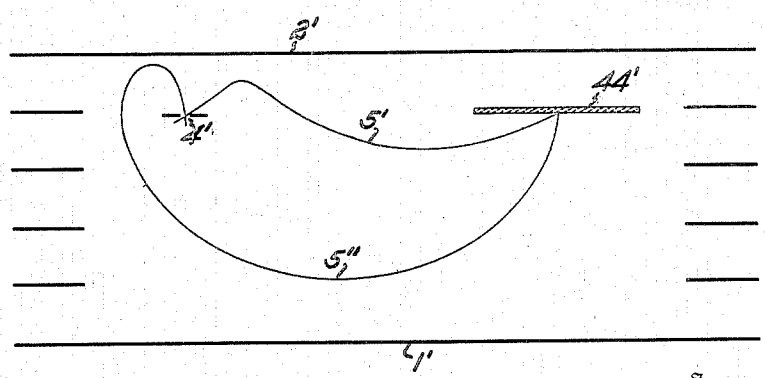


Fig. 1b.



Inventor:
Walker Bleakney
By Potter, Pierce & Scheffler
Attorneys.

Nov. 12, 1940. W. BLEAKNEY 2,221,467

FOCUSING AND SEPARATION OF CHARGED PARTICLES

Filed Dec. 27, 1938 4 Sheets-Sheet 2

Fig. 3.

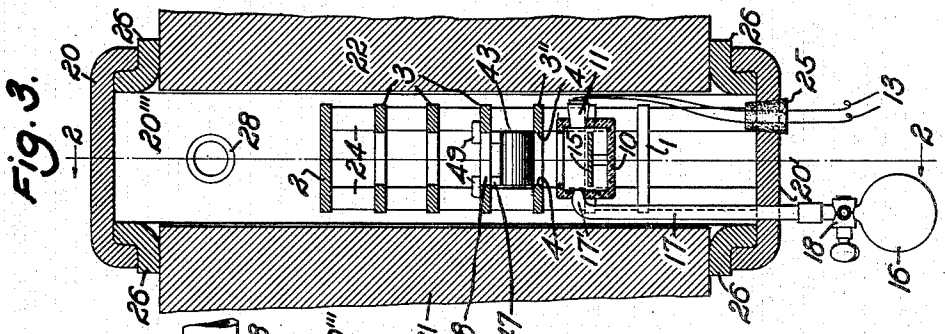
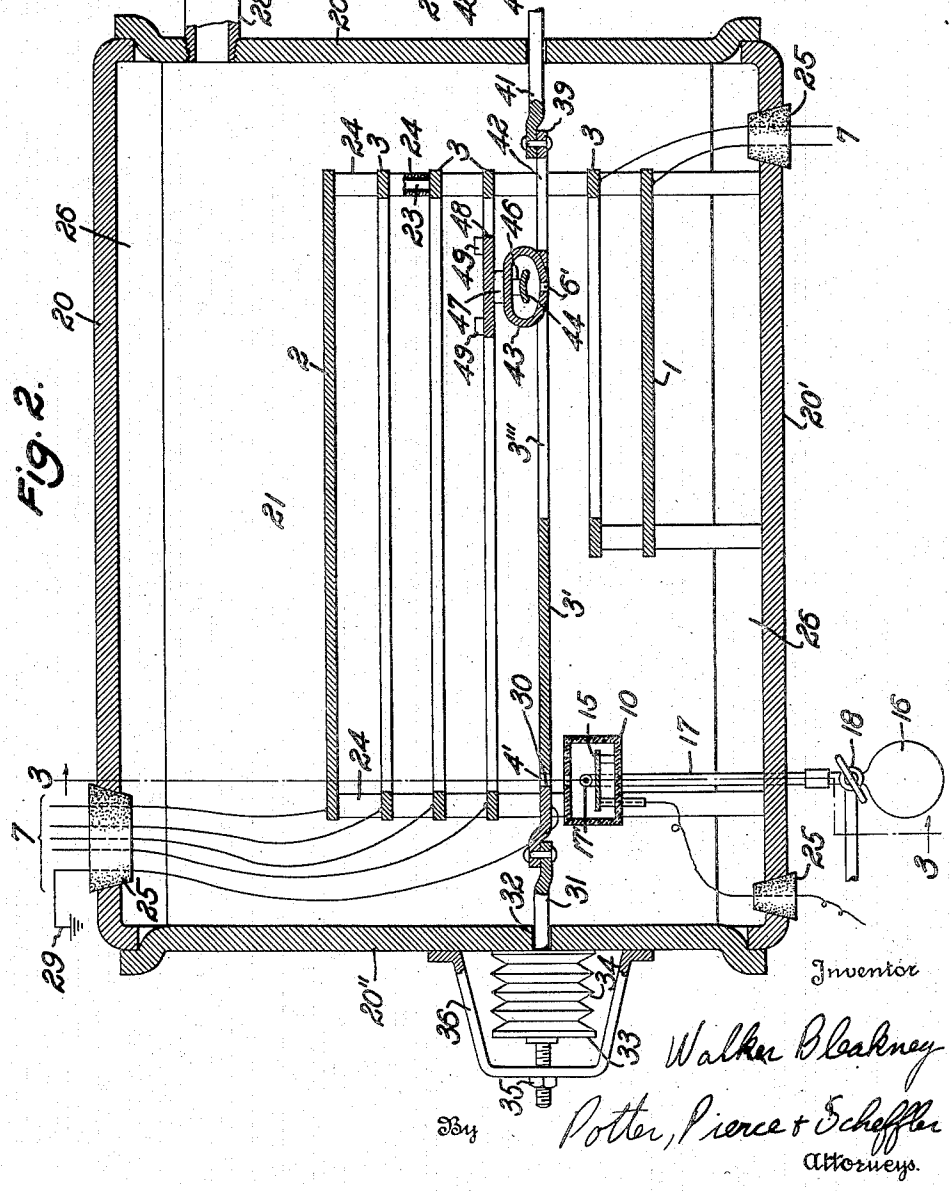


Fig. 2.



Inventor
Walker Bleakney
By Potter, Pierce & Scheffler
Attorneys.

Nov. 12, 1940. W. BLEAKNEY 2,221,467

FOCUSING AND SEPARATION OF CHARGED PARTICLES

Filed Dec. 27, 1938 4 Sheets-Sheet 3

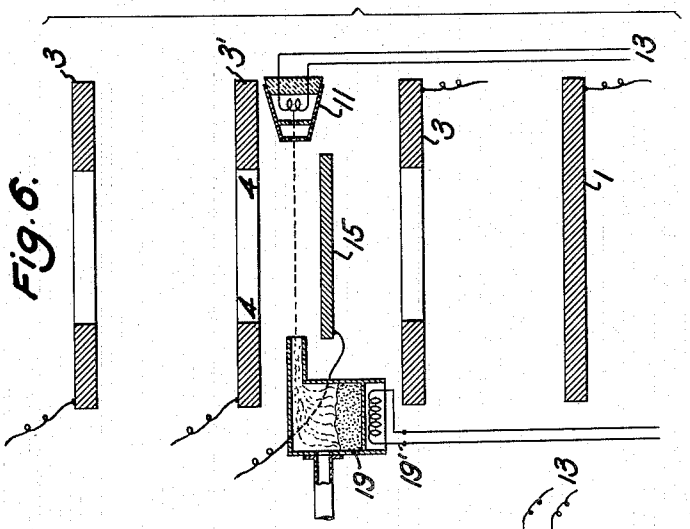


Fig. 6.

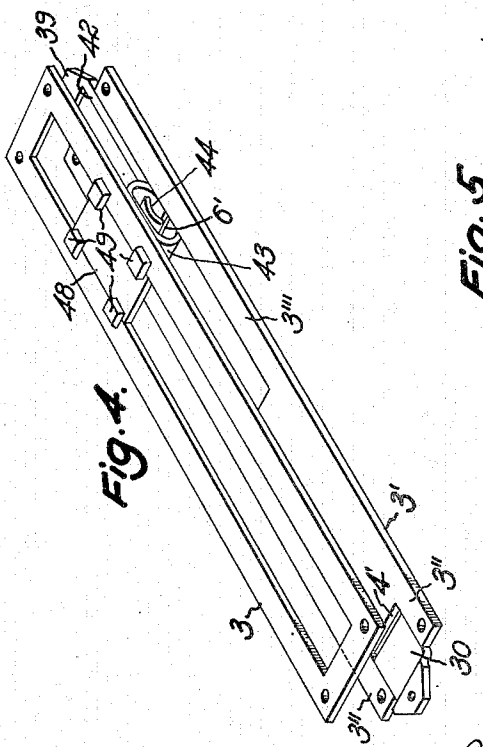


Fig. 4.

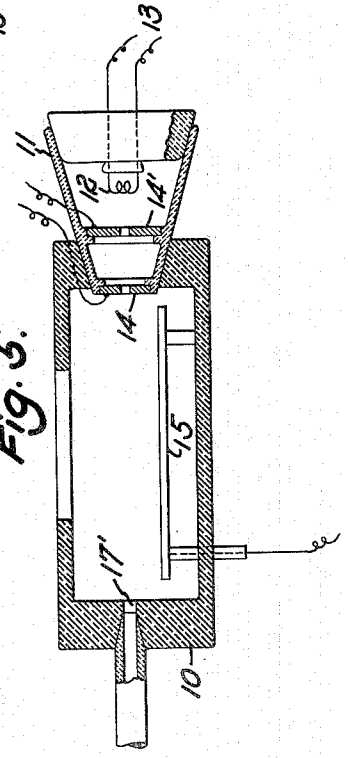


Fig. 5.

Inventor

Walker Bleakney

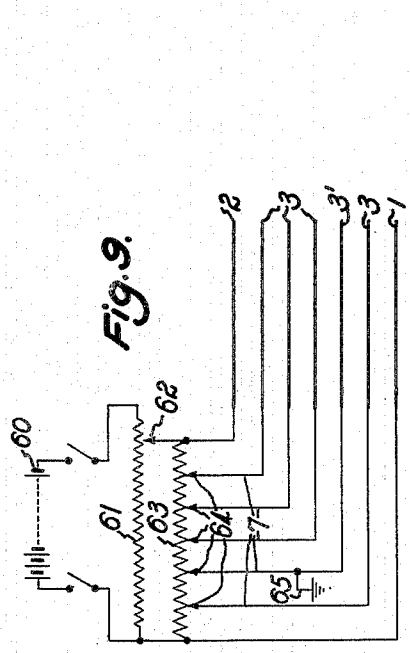
By Potter, Pierce & Scheffler

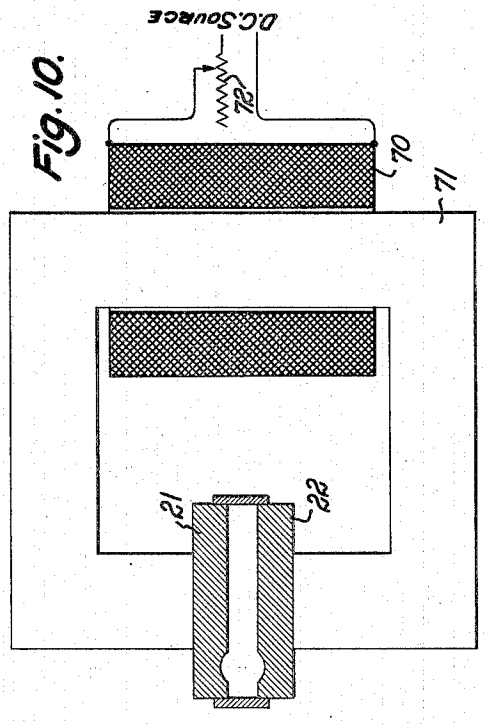
Attorneys.

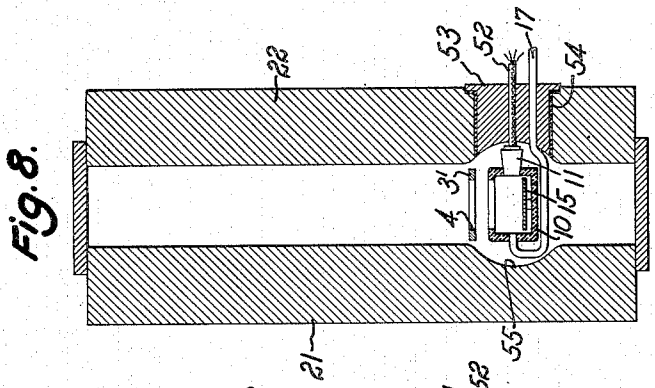
Nov. 12, 1940. W. BLEAKNEY 2,221,467

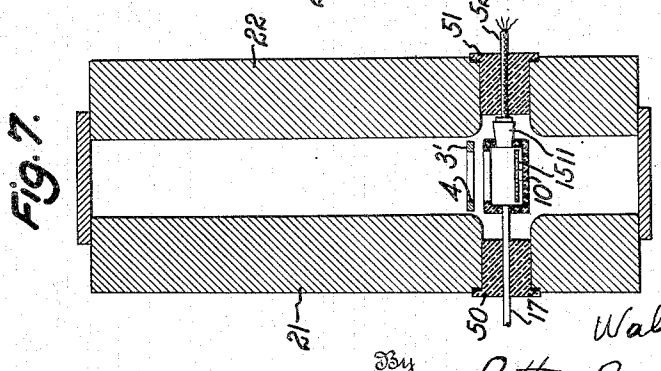
FOCUSING AND SEPARATION OF CHARGED PARTICLES

Filed Dec. 27, 1938 4 Sheets-Sheet 4









Inventor:
Walker Bleakney
By Potter Pierce & Scheffler
Attorneys.

Patented Nov. 12, 1940

2,221,467

UNITED STATES PATENT OFFICE

2,221,467

FOCUSING AND SEPARATION OF CHARGED PARTICLES

Walker Bleakney, Princeton, N. J., assignor to Research Corporation, New York, N. Y., a corporation of New York

Application December 27, 1938, Serial No. 247,978

8 Claims. (Cl. 250—157)

This invention relates to the focusing, separation and analysis of charged particles and particularly to the determination of the mass of particles of atomic dimensions by use of apparatus of the class known as mass spectrographs and mass spectrometers and broadly includes a method and apparatus for providing ionized particles from a sample of material and for subjecting the ionized particles to the analyzing effect of suitably coacting electric and magnetic fields.

A principal opject of the invention is to provide improved means for forming a separate and distinct image, for example, on a sensitized plate, for each different value of the "specific charge" or ratio of charge to mass possessed by the different ions included in a stream of source of ions.

Another object of the invention is to provide apparatus which will make distinct images of each of the species of ions according to their specific charge irrespective of the velocity and direction of the propagation of the ions entering the analyzing chamber, that is, at their source.

Still another object of the invention is to make available a mass spectrograph or the like with coacting electric and magnetic fields so arranged geometrically with respect to each other, the propagating source, and the receiver that improved final focusing is realized in an instrument of smaller than the usual size and independently of the velocity and direction of propagation of the entering ions.

Another object is to provide focusing means whereby charged particles are astigmatically projected upon a recording device so as to form a separate image thereon for each species of different specific charge.

A further object of the invention is the provision of means for creating a localized region of high density of gas or vapor favorable to the production of many ions.

Another object of the invention is to provide a method for producing ions in the more refractory materials which have insufficient vapor pressures at ordinary room temperatures.

The manner in which the above and other objects of the invention are realized will be pointed out in the description of the method and apparatus which follows, reference being had to the drawings in which:

Fig. 1 is a partial diagrammatic representation, in isometric perspective, of apparatus embodying the principles of the invention;

Fig. 1*a* is a diagram representing the forces utilized in the apparatus of Fig. 1;

Fig. 1*b* is a partial diagrammatic representation of a modified embodiment of the invention;

Fig. 1*c* is a diagram representing the forces utilized in the embodiment of Fig. 1*b*;

Fig. 2 is a vertical section, on line 2—2 of Fig. 3, of apparatus useful in practicing the invention;

Fig. 3 is a partial section on line 3—3 of Fig. 2;

Fig. 4 is an isometric perspective view of the electrode member 3' of Figs. 2 and 3 and associated adjusting means;

Fig. 5 is a detailed view in sectional elevation of the means for providing charged particles in the apparatus of Figs. 2 and 3;

Fig. 6 is a modified form of means for providing charged particles;

Fig. 7 is a sectional elevation of a portion of a modified apparatus;

Fig. 8 is a sectional elevation of a portion of a further modification;

Fig. 9 is a diagrammatic representation of a circuit for providing an electric field in the apparatus of the invention; and

Fig. 10 is a diagrammatic representation of means for providing a magnetic field in the apparatus of the invention.

Like parts are designated with the same symbols in all figures.

Figs. 1 and 1*a* diagrammatically indicate how the forces in the electric and magnetic fields act upon charged particles to cause them to form separate images for each ionic species of different specific charge. In the figures, numerals 1 and 2 designate flat metal plates insulated from each other and separately connected to energizing means so that they may be maintained at different potentials and an electric field established between them. A series of metal plates 3, 3' with interior portions removed, are maintained in spaced and insulated relationship between field terminal plates 1 and 2. Plates 3, 3' are maintained at intermediate potentials in order to maintain a very uniform electric field in the space defined by plates 1 and 2 and the openings in plates 3, 3'. The energizing means may be a storage battery, a direct current generator having very even voltage characteristics, or a circit including an alternating current source and comprising rectifiers and condensers to assure constant potentials on the several plates. It is essential that the voltage drop between plates 1 and 2 be maintained steady and at controlled values in order that non-fluctuating electric

fields of predetermined strength exist between the plates.

In order that a magnetic field may extend across space A, the casing enclosing the plate assembly may be positioned in a solenoid or positioned to take advantage of the earth's magnetic field, but I have found it convenient and otherwise advantageous to place the plate assembly between the poles of a powerful magnet large enough to provide a relatively uniform field. The magnetic field is set up in the direction indicated by z in Fig. 1*a*.

The sample of material to be analyzed is placed in means, to be described later, under slot 4—4 in plate 3' and gas or vapor molecules from the sample are ionized, that is, electrically charged, by a stream of electrons projected beneath and parallel to slit 4—4. An auxiliary electric field forces the charged particles through the slit and into analyzing space A. These charged particles travel through a trajectory of which curves 5 in Fig. 1 are typical and are brought to a focus at 6—6, represented as a slit in plate 3'.

The movement of charged particles from slit 4—4 to slit 6—6 is mathematically represented as follows. At any instant t the position of a particle passing through an electric field and a magnetic field, simultaneously, can be expressed by a plurality of equations which will contain terms for the strength of the electric field E, the strength of the magnetic field H and the initial velocity components u_0, v_0 and w_0 of the particle along the x, y and z axes, respectively. These equations can be solved simultaneously for the focal position thus making it possible to predict a definite focus for all charged particles with a given value of e/m, or specific charge; it is then found that in the x—y plane all charged particles with a given value of e/m are brought to a focus irrespective of the velocity components u_0, v_0 and w_0 with which the particles left the source 4—4 and entered into the analyzing chamber traversed by the electric and magnetic fields; in the z-direction, since this component (w) of the velocity is not affected by either the electric or magnetic fields, there will merely be a lateral displacement of the particle along this direction, i. e., in the direction of the magnetic field. For a range of values of w_0 this displacement in the z-direction leads to an astigmatic broadening of the image in the direction of the magnetic field, but results in no decrease in the separation of ions of different types.

The mathematical analysis of the problem is as follows:

A magnetic and an electric field are set up perpendicular to each other in a certain region of space. Let the magnetic field H be along the z-axis and the electric field E be along the y-axis. Now suppose a charged particle of mass m and charge e passes through the origin with a velocity whose components along the x, y and z axes are u_0, v_0 and w_0, respectively, as indicated in Fig. 1*a*. The differential equations of motion are known from the forces acting to be as follows:

$$m\frac{d^2x}{dt^2}=\frac{eH}{c}\frac{dy}{dt}$$

$$m\frac{d^2y}{dt^2}=Ec-\frac{eH}{c}\frac{dx}{dt}$$

$$m\frac{d^2z}{dt^2}=0$$

The solutions of these equations are well known to mathematicians. They are:

$$x=\frac{Ect}{H}+\frac{mc}{eH}v_0\left(1-\cos\frac{eHt}{mc}\right)-\frac{mc}{eH}\left(\frac{Ec}{H}-u_0\right)\sin\frac{eHt}{mc}$$

$$y=\frac{mc}{eH}\left(\frac{Ec}{H}-u_0\right)\left(1-\cos\frac{eHt}{mc}\right)+\frac{mc}{eH}v_0\sin\frac{eHt}{mc}$$

$$z=w_0t$$

Considering the projection of the motion in the x—y plane, the plane in which the focusing takes place, it is seen that when $t=0$, x and y are zero which means that the particle was at the origin when we started to measure time. At other times x and y have various values, but at the particular time

$$t=2\pi\frac{mc}{eH}$$

we find that

$$x=2\pi\frac{Emc^2}{eH^2}$$

$$y=0$$

At this point the initial conditions have been exactly reproduced except that the particle has been displaced along the x-axis, a distance inversely proportional to its specific charge e/m. It will be noted that in this plane, the x—y plane, the initial velocity and direction need not be considered and hence particles with all possible initial velocities and directions come to a focus at this point. However, from the above equation for z, it is evident that if there is initially a z component of velocity w_0 the focal point will be displaced in the z-direction; and for a range of values of w_0 the image of a point source will be a line perpendicular to the x—y plane, the astigmatic focus mentioned previously. The apparatus of the invention may be regarded as an e/m filter since out of a heterogeneous source it sorts out the particles according to their specific charges.

When the electric field E and magnetic field H have the directions shown in Fig. 1*a*, the particles will be moved along paths 5 in Fig. 1 if the particles are charged positively. When it is desired to measure and identify the particles that acquire negative charges in the ionizing operation, the potentials in the ionizing chamber and the directions of the electric and magnetic fields are reversed and the negatively charged particles will then be forced into and through analyzing space A.

As an example of the magnitudes involved, if the slit 6—6 is 30 centimeters from slit 4—4 and the magnetic field is of the order of 4500 gauss, ions of atomic weight 100 will be focused at slit 6—6 when the electric field is of the order of 100 volts per centimeter.

By reversing both the electrical and the magnetic fields, the trajectories of charged particles in the fields are inverted. Fig. 1*b* shows the trajectories of positively charged particles in fields directed as indicated in Fig. 1*c*. Since only the signs are changed and not the magnitude of the forces involved, the displacement of the focal point from the slit 4' of Fig. 1*b* is the same for a particle of identical specific charge as in the arrangement of Fig. 1. However, due to the inversion of the shape of the trajectories a somewhat different arrangement of apparatus parts is desirable. As is clearly apparent from Fig. 1*b*, both the curtate trajectories 5' and the prolate

trajectories 5'' are below the plane of focusing for a relatively large space adjacent the focus. This feature makes possible the use of a sensitive member of relatively large extent, for example, a photosensitive plate 44'. On the other hand, care in design is required to avoid excessive interference with the trajectories adjacent the source slit 4'.

The apparatus of Figs. 2 and 3 includes a casing with wall members 20, 20', 20'' and 20''' which, together with the pole pieces 21, 22 of a magnet, form a rectangular box enclosing the plate assembly used to provide a uniform electric field. While the casings may be made of glass, a material that permits visual observation of the contents of the casing after sealing, copper, nichrome, and particularly non-magnetic stainless steel, are generally preferable because of the strength and workability of these materials.

The casing may be constructed as a complete enclosure fitting between the poles of the magnet in which case side members are provided. These side members are adjacent and parallel to the pole faces of the magnet and hence may be made of iron since iron in this position merely extends the pole faces and contributes to the uniformity of the field.

In the form of apparatus shown in Figs. 2 and 3, non-magnetic stainless steel plates 20'', 20''' are welded to pole pieces 21 and 22, joining them and forming end walls of the case. Welded to the pole pieces between plates 20'', 20''' and extending along the top and bottom edges of the pole pieces are bent strips 26 having a re-entrant space for the reception of the bent edge plates 20, 20'. The free edges of plates 20'', 20''' are also bent outwardly and upwardly to provide spaces for the reception of the bent-down edges of plates 20, 20'. The side and bottom plates are welded in place before the ionizing and analyzing means are placed in the casing. The top plate is then welded or brazed or otherwise sealed on, provision being made, of course, for electrical and gas connections. The distance across the casing from pole face to pole face is usually kept below three inches. The height for a three-inch width may be about 15 inches, and the depth may be about 20 inches. Plates 1, 2, 3 and 3' are held in alignment by glass rods 23 spaced with glass spools or ferrules 24 over the rods. After assembly, the plates are placed in the casing with suitable electrical conductors 7 passing out through insulating plugs 25, for example, of glass, into which they are hermetically sealed and which are in turn sealed into the wall or plate of the casing.

Under the end of plate 3' and aligned with slit 4—4 is a source of ions shown more particularly in Fig. 5 and comprising a container 10 for the material to be ionized and tested, and an "electron gun" 11 for ionizing the atoms and molecules supplied to the container. The electron gun includes a wire 12 from which electrons are emitted and apertured plates 14 for accelerating the movement of the electrons. Wire 12 is heated by current flowing in circuit 13 and plates 14 are maintained at progressively higher positive potentials with respect to the potential of wire 12 as is understood by those familiar with electronic projection. The electrons are projected in a direction parallel to the direction of the magnetic field and parallel to slit 4—4. The electrons and the ions formed by collision of electrons and molecules respond to the force of an electric field and such a field is provided between insulated plate 15 and plate 3'. When plate 15 is held at a potential positive to the potential of plate 3', electrons and negative ions are attracted to plate 15 and positively charged particles are forced through the opening in the ionizing chamber and through slit 4—4.

Gases or vapors to be analyzed are supplied from a gas holder 16 connected to container 10 by means of tube 17 having a capillary orifice 17', and three-way cock 18 which permits supplying the gas sample to the holder with the analyzing apparatus shut off and from the holder to the analyzing apparatus with the supply tube shut off. The holder is advantageously evacuated to about 1^{-5} mm. Hg with the rest of the apparatus and then filled with the substance to be analyzed to a pressure of about 10^{-2} mm. Hg with the passage to the analyzing apparatus shut off.

Solid and liquid samples may be introduced into the analyzing space, as shown in Fig. 6, by placing them in an oven 19 heated by an electric heating element 19'. The material is vaporized into the space below slit 4—4 where it is ionized by electrons from electron gun 11.

The plate assembly for control of the electric field is made up of nichrome plates about ½ mm. thick and spaced 10 mm. apart as stated above with insulating spools 24 held in alignment by insulating rods 23 which pass through holes near the corners of the plates. Plate 3', as shown in Fig. 1, has openings 4—4 and 6—6 from 0.01 to 3 mm. in width and parallel to the magnetic field. The charged particles pass through slit 4—4 into the analyzing space A and through slit 6—6 in forming a new image of the original virtual image at slit 4—4. The trajectories of the particles may be computed from the formulae given above and the openings or cut-away portions of plates 3 and 3' may be determined from a graphical study of the trajectories, such as those shown in Figs. 1 and 1*b*. The openings cannot receive every charged particle passing through slit 4—4 but, by using limits of x and y in keeping with the dimensions of the analyzing fields and probable entrance angles, a large enough percentage of the particles are permitted to pass to the focus to give very accurate results.

In the apparatus of Figs. 2, 3 and 4, means are provided for further focusing after the apparatus has been assembled and tested. As shown in Fig. 4, plate 3' is constructed in the shape of an H with short arms 3'' at one end and longer arms 3''' at the other end. A filler plate 30 of the same thickness as plate 3' fits between arms 3'' and is held in the plane of plate 3' by a rod 31 which passes through an opening 32 in casing wall 20'' and through the cover plate 33 of a very flexible metal bellows 34, the open end of which is attached to wall 20''. The threaded end of rod 31 is secured by a nut 35 after it passes loosely through a bracket 36 attached to wall 20''. Bellows 34 is sealed with gas-tight joints to the casing and to rod 31 and so permits longitudinal movement of rod 31, by turning nut 35, without entrance of air into the casing. With this arrangement the inner edge of auxiliary plate 30 can be held at any desired distance from that edge of plate 3' between arms 3'', 3'' and so form a slit 4' of any desired width.

Slit 6, for reception of the charged particles of selected e/m, could be similarly varied in width, but in Figs. 2 and 3 it is shown as an opening 6' of constant width in an enclosure 43 which

can be adjusted as to distance from slit 4' as will be later described. Enclosure or shield 43 is made of a flattened tube or piece of bent sheet of non-magnetic metal of such length that the lower edge or edges fit between arms 3''' of plate 3'. Opening 6' at the bottom of the shield is in the plane of plate 3'. Within shield 43 is a target or image receiving member 44 which extends parallel to and immediately over slit 6' its entire length. Target 44 is held in position by insulators 46 preferably attached to the inner top surface of shield 43 adjacent the ends thereof. Shield 43 is supported by insulators 47 from a horizontally extending shield member 48 which in turn is held in the plane of the plate 3 that is immediately above plate 3' by short thin clip members 49 of conducting material, said clip members being fastened to the top of member 48 at its ends and resting upon, but not fastened to, the top surface of plate 3. A narrow member 42 is attached to each end of member 43 and these extend along and out beyond the respective surfaces of arms 3''' to a cross connecting member 39. Member 39 is fastened to a rod 41 which passes through casing wall 20''' in movable manner similar to that of rod 31 in wall 20'' and permits the assembly in which slit 6' is comprised to be positioned horizontally from outside the casing. Member 48 is in electrical contact with plate 3 through members 49 and is consequently held at the potential of plate 3. This is a pertinent relationship where a uniform electric field is desired. Member 43 is at the potential of plate 3'. Member 44 is preferably the terminal of a sensitive electrometer and a conductor (not shown) passes through the wall of the casing and connects member 44 to the electrometer outside the casing.

All particles entering through slit 6' will have a definite specific charge e/m as explained above and it is important that no charged particles strike image receiving member 44 which approach from any other direction than through the slit. Shield 43 gives such protection to member 44 and yet permits particles to approach the slit from both sides as shown diagrammatically in Fig. 1. Shielding member 48 prevents member 43 from disturbing the uniformity of the electric field above it and so causing deflections of many particles that would, in a uniform field, enter slit 6'. Few if any of the particles that are stopped by member 48 are of the same e/m as those capable of entering slit 6'.

Figs. 7 and 8 show modified forms of the apparatus of the invention. In these forms of the apparatus a more effective use of the space between the pole faces establishing the magnetic field by providing suitable cavities in the pole pieces into which the ends of the ionizing container 10 may be projected. In this manner, the length of slit 4—4 may more nearly approach the width of the magnetic field, making possible a greater sensitivity of the analyzing device either by increasing the supply of ionized particles to the analyzing fields or by increasing the available magnetic field strength by permitting the pole pieces to be brought closer together.

In the form shown in Fig. 7, container 10 is mounted between two cylindrical insulating plugs 50 and 51 which may be inserted in a gas-tight manner in pole pieces 21, 22. Plug 51 carries cable 52 which includes the electrical connections for the electron gun 11, plate 15 and the vaporizing device for the sample, if such a device is utilized. The sample is supplied through tube 17 carried by plug 50.

In the form shown in Fig. 8, both the cable 52 and the supply tube 17 are carried in the plug 53 which is inserted in pole piece 22. The plug is sealed and insulated from the pole piece by means of insulating bushing 54. A cavity 55 of suitable shape is provided in the face of pole piece 21 to receive the end of the chamber 10.

In Fig. 9 is diagrammatically shown a suitable arrangement for establishing and controlling the electric field in the apparatus. A direct current potential from battery 60, or other suitable source of direct current potential is connected across resistance 61. Plate 1 is connected to one end of the resistance 61 and plate 2 is connected at a suitable position on the resistance by means of adjustable contactor 62, whereby the overall potential drop may be varied. The intermediate plates 3, 3' are connected to proper points on resistance 63 by means of fixed or adjustable connectors 64. Plate 3' is preferably grounded as shown at 65.

It is to be appreciated that while the drawings show a series of parallel plates 3, which are to be maintained at regularly increased potentials, as means for obtaining a uniform electric field, such field can also be obtained with a helix of high resistance wire having a current of sufficient magnitude through it to provide the necessary voltage drop from one end of the coil to the other. Also, bounding plates covered with a poorly conducting coating across which a current is caused to flow will give a uniform field within and parallel to the bounding surface.

In the means for providing and regulating the magnetic field shown diagrammatically in Fig. 10, the field is produced between pole pieces 21, 22 by means of coil 70 surrounding core 71. The coil is energized from a suitable source of direct current and the strength of the magnetic field may be varied by means of the adjustable resistance 72 interposed in the direct current supply leads to the coil 70.

It is desirable that the casing and contents be "degassed" at elevated temperature, say, 200° C., before the apparatus is operated. While the apparatus is being evenly raised in temperature the vacuum pump connected to outlet 28 is operated to provide as low a pressure within the casing as possible. The vacuum pump is usually operated throughout the analysis of samples and an absolute pressure of less than 10^{-5} mm. Hg is desirable.

It will be seen that the invention provides a method and apparatus for analyzing charged particles according to their specific charge whereby ionized particles are introduced into an electric field wherein they are subjected to the action of a magnetic field having a direction normal to the direction of the electric field, the strengths of the field being adjusted to bring substantially all of the charged particles of like specific charge to a focus on a receptor of a device sensitive to charged particles.

This application is a continuation-in-part of my application Serial No. 187,537, filed January 28, 1938.

I claim:

1. Apparatus for analyzing charged particles with respect to their specific charge comprising a plurality of parallel electrode members defining a space and providing a constant substantially uniform electric field within said

space, pole members providing a magnetic field within said space normal to said electric field, one of said electrode members having a slot therein parallel to the direction of the magnetic field, means for projecting a sample of charged particles into said space through said slot including a chamber positioned between said pole members and projecting into cavities in the faces thereof, means for supplying material to be analyzed to said chamber, means for projecting electrons through said chamber, and means sensitive to charged particles positioned in said space in the plane of said slotted electrode and spaced from said slot in a direction normal to the magnetic field.

2. Apparatus for analyzing charged particles with respect to their specific charge comprising means providing a magnetic field, a plurality of substantially parallel electrode members disposed within said magnetic field in planes substantially parallel thereto and defining a space therein, means energizing said electrodes to provide an electric field within said space normal to said magnetic field, one of said electrodes having an aperture therein for the admission of charged particles into the space defined by said electrodes, means for projecting a beam of charged particles through said aperture into said space, and means sensitive to charged particles positioned in said space in the plane of said apertured electrode and spaced from said aperture in a direction normal to the magnetic field.

3. Apparatus for analyzing charged particles with respect to their specific charge comprising means providing a magnetic field, a plurality of substantially parallel electrode members disposed within said magnetic field in planes substantially parallel thereto and defining a space therein, means energizing said electrodes to provide a constant electric field within said space normal to said magnetic field, one of said electrodes having an aperture therein for the admission of charged particles into the space defined by said electrodes, means for projecting a beam of charged particles through said aperture into said space, and means sensitive to charged particles positioned in said space in the plane of said apertured electrode and spaced from said aperture in a direction normal to the magnetic field.

4. Apparatus for analyzing charged particles with respect to their specific charge comprising means providing a magnetic field, a plurality of substantially parallel electrode members disposed within said magnetic field in planes substantially parallel thereto and defining a space therein, means energizing said electrodes to provide a constant substantially uniform electric field within said space normal to said magnetic field, one of said electrodes having an aperture therein for the admission of charged particles into the space defined by said electrodes, means for projecting a beam of charged particles through said aperture into said space, and means sensitive to charged particles positioned in said space in the plane of said apertured electrode and spaced from said aperture in a direction normal to the magnetic field.

5. Apparatus for analyzing charged particles with respect to their specific charge comprising means providing a magnetic field, a plurality of substantially parallel electrode members disposed within said magnetic field in planes substantially parallel thereto and defining a space therein, means energizing said electrodes to provide an electric field within said space normal to said magnetic field, one of said electrodes having an aperture therein for the admission of charged particles into the space defined by said electrodes, means for projecting a beam of charged particles through said aperture into said space, means sensitive to charged particles positioned in said space in the plane of said apertured electrode and spaced from said aperture in a direction normal to the magnetic field, and means for progressively varying the strength of at least one of said fields.

6. Apparatus for analyzing charged particles with respect to their specific charge comprising means providing a magnetic field, a plurality of substantially parallel electrode members disposed within said magnetic field in planes substantially parallel thereto and defining a space therein, means energizing said electrodes to provide an electric field within said space normal to said magnetic field, one of said electrodes having an aperture therein for the admission of charged particles into the space defined by said electrodes, means for projecting a beam of charged particles through said aperture into said space, means sensitive to charged particles positioned in said space in the plane of said apertured electrode and spaced from said aperture in a direction normal to the magnetic field, and means for progressively varying the strength of said electric field.

7. Apparatus for analyzing charged particles with respect to their specific charge comprising means providing a mangetic field, a plurality of substantially parallel electrode members disposed within said magnetic field in planes substantially parallel thereto and defining a space therein, means energizing said electrodes to provide an electric field within said space normal to said magnetic field, one of said electrodes having an aperture therein for the admission of charged particles into the space defined by said electrodes, means for projecting a beam of charged particles through said aperture into said space, and means sensitive to charged particles adjustably positioned in said space in the plane of said apertured electrode and spaced from said aperture in a direction normal to the magnetic field.

8. Apparatus for analyzing charged particles with respect to their specific charge comprising means providing a magnetic field, a plurality of substantially parallel electrode members disposed within said magnetic field in planes substantially parallel thereto and defining a space therein, means energizing said electrodes to provide an electric field within said space normal to said magnetic field, one of said electrodes having an aperture therein for the admission of charged particles into the space defined by said electrodes, means for projecting a beam of charged particles through said aperture into said space including a chamber, means for supplying material to be analyzed to said chamber and means for projecting electrons through said chamber, and means sensitive to charged particles positioned in said space in the plane of said apertured electrode and spaced from said aperture in a direction normal to the magnetic field.

WALKER BLEAKNEY.